



## Final Report for Publication

# MASTER

## Managing Speeds of Traffic on European Roads

Contract No RO-96-SC.202

### Project

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## **Abstract**

This Final Report of the project MASTER (*MANaging Speeds of Traffic on European Roads*) summarises the results of the two-year research project. The main objective was to develop recommendations for speed management strategies and policies. Present speeds and speed management methods in Europe are described. The various impacts of speed are examined. A procedure for assisting decision-makers to determine appropriate levels of speed on different kinds of roads is outlined. Factors affecting drivers' choice of speed are studied. Different speed management measures and tools are assessed on the basis of literature studies, simulator experiments and field studies. Recommendations for speed management measures and tools are presented separately for four different road categories: urban residential streets, urban main roads, rural mixed traffic roads and motorways. It is concluded that further development of speed management could include, for example, harmonisation of speeds and speed limits in different countries, development of European guidelines for speed management on different kinds of roads, improvement of road design, further development and wider use of automated speed enforcement, and introduction of adaptive in-vehicle speed limiters.



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## Partnership

The MASTER project was developed by the following consortium:

**Project Coordinator:**

VTT Communities & Infrastructure (VTT, Finland):

**Partners:**

FACTUM Chaloupka, Praschl & Risser OHG (FACTUM, Austria)

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## Executive Summary

The aim of the project MASTER (*MAnaging Speeds of Traffic on European Roads*) was to produce information for the preparation of national and EU decisions concerning speed management strategies and tools. The results of the project are documented in 26 reports: 12 deliverables and 14 working papers. This report presents a summary of the project.

### **BACKGROUND**

The project MASTER arose primarily from concerns about the contribution of speed to accidents causing death and injury. Several studies have confirmed that reductions in the average driving speed result in reductions in the number and severity of accidents. Moreover, the accident rate on a given road increases with the speed variance. These observations indicate that achieving lower and more even speeds would reduce the number of accidents and mitigate their outcome.

However, it is recognised that accident prevention and casualty reduction as an objective of speed management has to be pursued with due consideration of other effects. More specifically, it is important to take into account the impacts on journey-times, vehicle operating costs, exhaust emissions and noise, and the acceptability of levels of speed to road users of all kinds and to others affected by them. All these effects of levels of speed must therefore be assessed comprehensively in the context of speed management.

### **OBJECTIVES**

The objective was to produce information that can be cited in the preparation of national and EU decisions concerning speed management strategies and tools. For this purpose, the project looked for answers to three key questions:

1. What are acceptable ranges of speeds?
2. What are the key factors influencing drivers' choice of speed?
3. What are the best speed management tools and strategies?

The answer to the first question determines the target ranges of speed for different kinds of roads, environmental conditions and driving situations. The answer to the second question provides information for the assessment of measures and tools, existing and potentially available, that can be applied for adoption of target ranges of speeds. The answer to the third question builds on the answers to the other two questions and provides recommendations for practical formulation of rational speed management strategies and policies, and for application of best speed management measures and tools in different situations.



## ***PRESENT SPEED MANAGEMENT METHODS***

Posted speed limits are the backbone of speed management in Europe. Speed is limited on all roads except for some sections of German motorways. There are also specific speed limits for heavy vehicles and novice drivers. Variable speed limits are used to some degree, usually on motorways or other high volume roads. Compliance to speed limits is enforced by the police, although there are differences between countries in the intensity and tolerances of the enforcement and penalties for speeding. Physical measures like speed humps and road narrowings are used for speed management in increasing numbers in urban areas. Information campaigns about the dangers of speeding are used to support speed management.

The responsibility for speed management is typically divided between several national and local authorities. The roles of the European Community and vehicle manufacturers are rather minimal. Even though there is co-operation between authorities, speed management can largely be seen to consist of independent actions without a distinctive integrated long-term plan. This is the case especially in urban areas where the views of local authorities regarding speed management can vary significantly within and between countries.

## ***PRESENT SPEEDS AND SPEED LIMITS***

There are great variations in speed limits on similar roads in Europe. Only in urban areas speed limits are broadly in harmony. Urban speed limit is generally 50 km/h, with few exceptions of 60 km/h. Speed limits on rural mixed traffic roads range from 70 to 113 km/h. Speed limits on motorways vary between 80 and 130 km/h, even though these roads have fairly similar standards across Europe. Furthermore, some motorway sections in Germany have no speed limit at all.

Speed limits are typically set for safety reasons, and reflect road and traffic conditions. But deeper reasoning behind the selection of the prevailing values of speed limits is usually vague, and there is little evidence that present speed limits are optimal from the viewpoint of society, the road transport system, or the individual road user. In general, the determination of desired speed levels (and consequently speed limits) should be based on more explicit criteria and more systematic and comprehensive assessment of all impacts of speed.

Drivers frequently exceed the speed limit with up to 80 per cent speeding. This indicates that speed limits need to be supported by other measures to keep speeds at desired level. Speeding occurs especially on low speed urban roads and on motorways. Data from some countries indicate that driving speeds and speeding are systematically increasing.

## ***IMPACTS OF SPEED***

**Accidents:** On roads of a given type, injury accident rate, severe injury (including fatal) accident rate and fatal accident rate increase roughly as the 2nd, 3rd and 4th powers of





the mean traffic speed. Studies summarising findings from before-and-after studies of the impacts of speed on accidents have resulted in a rule of thumb saying that a 1 km/h decrease in mean speed causes a 2 to 3 per cent reduction in injury accidents. Work within MASTER on speed-accident relationships has demonstrated that cross-sectional log-linear statistical modelling offers the prospect of cross-national models that could estimate the effects of choice of speeds upon accident frequencies on particular categories of road in a range of Member States.

**Environmental impacts:** Emissions from road transport consist of a variety of pollutants, which are produced in different quantities at different speeds. The major pollutants are oxides of nitrogen whose emissions increase with speed, hydrocarbons whose emissions generally decrease with speed, and carbon monoxide and particulate matter whose emission levels are lowest at medium speeds. Carbon dioxide emissions are proportional to the amount of fuel consumed. Changes in speed can make a large contribution to emissions and in particular acceleration can cause disproportionate emissions. At speeds above 40-50km/h noise from traffic increases linearly with speed. Acceleration and braking cause a small increase in noise. Road humps and similar devices may cause extra noise due to movement of bodywork and contents of vehicles.

**Costs to users of vehicles:** Speed affects the users of the vehicles by changing the time spent on the journey and the vehicle operating costs. Some changes in costs in terms of time and money may be quite accurately perceived by the users; other changes may be appreciably or even substantially misperceived. Misperception does not affect the incidence of the changes in cost, but does affect the users' response to the changes. Nor do changes in costs to users imply equal changes in cost as reckoned by governments from the point of view of society. Whereas monetary and other material costs to vehicle users mount up in value additively whether they are incurred in a few large increments or many smaller ones, it is strongly debated whether the same is true of changes in travel time.

**Distributional impacts:** In principle, appropriate or target ranges of speed for any road could be determined by choosing speeds where the total benefits in relation to total costs are highest. Such method, however, does not take into account distributional impacts, the fact that gains from changes in speed for one group of people often mean losses to some other group. Another related concept is 'equity', which refers to the ethical desirability of distributing benefits or wealth among groups and individuals, and to the corresponding injustice caused by substantial uncompensated losses. From society's point of view equity and distributional impacts can be equally important to overall efficiency, sometimes even more important.

**Network level impacts:** If speed management permanently changes the accessibilities of locations in relation to each other, spatial socio-economic effects may occur in the long run. People and companies can move to other locations where some other mode of transport may be more attractive than the one used previously. Studies on the impacts of changes in speed often consider only *link level* impacts, which usually means assuming



that traffic volumes remain unaffected. *Network level* studies that take into account also the indirect impacts on traffic volumes are more laborious and rare.

### **FRAMEWORK FOR ASSESSING THE IMPACTS OF SPEED**

It is helpful for the decision-makers to be as fully informed as is practicable about the effects that any speed management policies and measures they are considering may have. This is helpful not only to their own decision-making, but also in their task of consulting the affected people and assessing the acceptability to them of the envisaged policies and measures. The MASTER framework for assessing the effects of traffic speed was developed and tested for these purposes.

The MASTER framework is a tool for systematic and comprehensive assessment of the impacts of (changes in) speed. The point of departure was social cost-benefit analysis including the assessment of both the magnitude and distribution of impacts. It is recognised that not all impacts can be expressed in monetary terms. The framework can be seen as collection of rules that guide the assessment process, rather than a "black box" which mechanically calculates effects. The main phases of the assessment process are:

1. description of the case to be assessed;
2. decision of the scope of the assessment (link level or network level) and which impacts (e.g. accidents, emissions, travel time, vehicle operating costs, route choice) are relevant to the case in question;
3. determination of impact functions or models (e.g. relationship between speed and accidents);
4. calculation of impacts according to the selected impact functions;
5. valuation of impacts in monetary terms for impacts for which it is deemed appropriate;
6. analysis of non-quantifiable impacts;
7. analysis of distributional impacts;
8. sensitivity tests;
9. presentation of results.

The output from the application of the framework should include all essential knowledge, not only the results, but also the data and assessment methods used. The whole assessment process in the MASTER framework is meant to be transparent and open to debate. It is recognised that quantitative effects on different scales, and qualitative effects often cannot be aggregated without considering their relative weights. This is left to the decision-makers.

A standard Excel spreadsheet was developed for practical application of the framework. The use of the framework is illustrated in a real life example. Tests have confirmed that the difficulties in the use of the framework lie largely in the ability of the user to specify impact functions and models, and assemble the range of data required to implement it.



## **DRIVERS' CHOICE OF SPEED**

Drivers' choice of speed is affected by the driving speed of fellow road users and by how people evaluate the opinions and reactions of significant others (family, friends, passengers, the police and the government). The relative importance of attitudes and social norms depends on the kind of road in question. People are not only subject to but also exert social influences. Information campaigns can make use of this fact. People's intentions and behaviours are also affected by the control people think they have over their behaviour. People not only have the feeling that it is difficult to control driving speed behaviour, but they also overestimate their own ability to control the consequences of speed.

Interviews of drivers and pedestrians in six countries indicate clear dissatisfaction with current levels of speed, in terms of the quality of urban life as well as road safety. There is a readiness at least in principle to see speeds reduced. This indicates that, notwithstanding current choices of speed by drivers, the climate for speed management policies for moderating speed may well be favourable.

Speed enforcement can significantly decrease speeds. Modern technology offers several cost-efficient means for speed enforcement provided that the driver does not necessarily have to be identified, but instead the owner of the vehicle can be held responsible. Speed reductions by road design can be achieved by isolated physical measures (e.g. speed humps, horizontal deflections, roundabouts, road surface treatments and rumble strips) or integrated measures like traffic calming zones in urban areas. Such physical measures typically force road users to reduce speed, instead of persuading them to reduce speed voluntarily. A preferable solution would be to design roads so that they are "self-explaining". By designing a road that provides a speed image that is in accordance with the actual speed limit, drivers will be led to choose appropriate driving speeds.

Speed behaviour also depends on road category and design. In practice, road categories are defined by a set of characteristics on several dimensions such as lane width, road surface and delineation. Results from simulator studies indicate that providing redundant information is not useful since drivers use only a few of the available characteristics for individual road classification. Correct classification can only be enabled if the few dimensions that are used by road users always provide consistent and correct information on the type of road. It appears to be best to identify those dimensions such that differences among categories are learnt most easily. Only specific dimensions such as lane width and the presence of bicycle lanes seem to affect drivers' speed choice directly.

To meet drivers' expectations consistently, a limited set of road categories that are maximally distinguishable from each other by the road users is needed, with appropriate speed levels dependent on the function of the road. The design elements of the road should consistently reflect the road category and thus support correct choice of speed. The results indicate that a more systematic application of road design elements could result in a subjective road categorisation that is more in correspondence with the



officially intended functions of the road, and in a reduced variation in driving speeds within a given road category.

### ***INNOVATIVE SPEED MANAGEMENT TOOLS***

Advanced Transport Telematics (ATT) can be used, for example, for giving drivers individual feedback of their speed, and for restriction of maximum speed according to prevailing road and traffic conditions by means of an adaptive in-vehicle speed limiter. ATT and traditional speed-reducing systems and measures were reviewed and the most promising of them tested in driving simulator. Furthermore, adaptive in-vehicle speed limiters were tested in real traffic in three countries. The results show that intervening systems are more effective in reducing speeds. Informative systems, on the other hand, appear to be more acceptable to drivers.

According to simulator studies, the provision of speed advice to drivers does result in reduced speed in curves. It seems to matter little exactly in what mode this advice is given to drivers. As would be expected optimal performance is attained under an automatic system, although further research should evaluate likely long-term benefits and behavioural adaptation issues. Dynamic speed control reduced significantly the mean speed and speed variance, as compared to advisory systems. The reduction in speed was especially high at village entries. However these benefits should be considered in the light of potential safety costs such as reduced following distances and possible complacency and loss of vigilance.

In the field studies of adaptive in-car speed limiter, the test drivers drove the same test route with the same car both with and without the speed limiter. Speed limiter reduced statistically significantly the mean driving speeds in urban areas, where the speed limit was between 30 and 60 km/h. On most test sections the reduction was several kilometres per hour. On rural mixed traffic roads with speed limits between 70 and 90 km/h the effects on mean speed were smaller and significant only on 70 km/h road sections, possibly because of congested driving conditions on roads with a speed limit of 80 or 90 km/h. The test sections on motorways had a speed limit of 110 or 120 km/h and because of high traffic volumes the mean speed of traffic was 5 to 10 km/h below the speed limit. Consequently, speed limiter had little effect on mean speed on motorways. However, the speed limiter effectively eliminated momentary high speeds on all types of road. The results of the field tests are best generalised to conditions when travelling in metropolitan areas, close to urban areas and inside towns and cities. There were hardly any conditions in which drivers could drive longer periods of time freely choosing their speed level.

### ***CURRENT KNOWLEDGE OF SPEED MANAGEMENT MEASURES AND TOOLS***

The total of 25 different speed management measures and tools are systematically described and assessed in terms of impact on speeds, other significant impacts, cost-effectiveness, and other relevant information. The measures are categorised as



informative and legal measures, measures related to road design and intervening measures, and interactions between measures are discussed.

### **RECOMMENDATIONS FOR SPEED MANAGEMENT**

The basic principles, on which recommendations for speed management are based, consistent with the objectives of the Common Transport Policy, are set out. One of the key principles is that the determination of target ranges of speed is based on a comprehensive assessment of the various impacts of speed. Only then it can be ascertained that the resulting speeds reflect the socially desirable balance of all impacts of speed, and equitable distribution of these impacts between different groups in the population.

The following recommendations were made for general development of speed management measures, tools and policy:

1. Speed limits on roads of similar classification in different European countries should be harmonised so that road users' expectations are consistent with respect to correct choice of speed irrespective of previous driving experiences in their home country. These speed limits should reflect the socially desirable speeds.
2. European guidelines are needed for application of speed management measures and tools on residential and main roads in urban areas and on rural mixed-traffic roads. This would promote consistent and cost-effective speed management.
3. Preparations for the introduction of compulsory adaptive speed limiters should be started. Adaptive speed limiters automatically prevent speeding by adjusting speeds according to the prevailing speed limit. The first step could be large-scale field experiments in urban areas in different countries.
4. Road design should be developed in order better to support drivers' correct choice of speed. This could be achieved by hierarchical categorisation of roads into a limited number of categories so that each category has a distinct set of characteristics that is clearly different from that of other categories, according to the principle of self-explaining roads.
5. Automated speed enforcement should be developed further and taken into wider use. To improve the cost-effectiveness of automated enforcement, legislative changes are needed in some countries so that the owner of the vehicle can be held responsible for speeding offences. Cost-effectiveness could be further improved if all vehicles were equipped with an electronic identification device. Such device would be useful also for other purposes, e.g. tracing stolen vehicles and collection of parking fees.
6. Speed management would benefit from the reduction of the difference between the effects of speed on social and private costs. If the cost of increasing (or decreasing) driving speed as experienced by drivers would follow more closely the respective cost to the society, drivers would voluntarily choose speeds that are closer to socially optimal speeds. In principle, this could be achieved by internalising external



costs, e.g. accident costs and environmental costs. However, further research is needed to find out if and how this could be realised in practise.

7. Information and publicity campaigns regarding the impacts of speed are needed, with the purpose of giving objective information about all impacts of speed. Such information could increase the public acceptance of speed restrictions that are justified from society's viewpoint. Nevertheless, decision-makers will still need to recognise that popularity is not necessarily a good criterion for speed management policies.
8. Speed limits should be extended to cover all roads in Europe, and the highest possible speed of vehicles should be restricted to the highest speed limit on motorways.

In addition, recommendations for speed management measures and tools are proposed for four different road categories: urban residential streets, urban main roads, rural mixed traffic roads, and motorways. These categories cover practically all roads and they typically differ from each other in respect of road geometry, environment, speeds and safety problems. For each category its key features and present speeds are discussed and recommendations for short-term and long-term speed management are made.

#### **RECOMMENDATIONS FOR FURTHER RESEARCH**

Further research is needed in several areas before the recommendations above can be fully, correctly and effectively implemented. Especially, speed management could benefit from research on

1. the impacts of speed on the various exhaust emissions, noise, vehicle operating costs and time costs;
2. network level effects of speed management;
3. the use of different kinds of roads in the course of different kinds of journeys;
4. the impacts of changes in speeds on accidents generally, and the impacts of adaptive in-vehicle speed limiters on accidents especially;
5. monetary valuation of the impacts of speed, especially the value of time, environmental impacts and accidents;
6. methods for assessing the distributional and equity impacts of changes in speed;
7. standardisation of collection and reporting of speed data;
8. adaptive in-vehicle speed-limiters with respect to their potential for improving speed behaviour in adverse weather and road surface conditions, behavioural adaptation effects, acceptability, and human-machine interfaces.



# 1 GENERAL PRESENTATION OF THE MASTER PROJECT

## 1.1 BACKGROUND

The project MASTER arose primarily from concerns about the contribution of speed to the number and severity of accidents causing death and injury. Several studies have confirmed that reductions in average driving speed result in reductions in the number and severity of accidents (see e.g. *Andersson & Nilsson 1997, Elvik et al. 1989, 1997, Finch et al. 1994, Ranta & Kallberg 1996*). Moreover, it has been shown that the higher the speed variance the higher the accident rate is on a given type of road. In addition, the speed variance increases with the proportion of vehicles exceeding the speed limit (*Baruya 1998c*). These observations indicate that achieving lower and more even speeds is an effective measure to reduce the number of accidents and mitigate the outcome of a collision.

Clearly, vehicle speed is a key factor in road safety, and the driver who makes the speed choice is the decisive part in the road-vehicle-human system. The driver's actual speed choice depends on various factors. It depends partly on the road environment and the driving situation, and partly on his intention to adapt (or not adapt) to the speed limit, and on his speed habits. The choice of speed is also influenced by the driver's subjective assessment of the risk of becoming involved in an accident or getting a penalty for speeding. Drivers may speed for a variety of reasons such as impaired judgement through alcohol and other drugs or they may simply be in a hurry. Many drivers maintain a speed in excess of the posted limit but below a level at which they believe they will be cited. In addition, drivers may engage in inadvertent speeding whereby they fail to realise they are travelling too fast for the environment (e.g. junctions, curves, motorway exits, construction zones). Finally, drivers who have been driving at a high speed for an extended period (e.g. on a motorway) may become habituated to the speed and overestimate the degree by which they are lowering their speed when arriving zones where slowing down is required.

Posted speed limits are the backbone of speed management in all countries. But speed management is concerned not only with the setting and enforcing of speed limits (to discourage or prevent *excess speeds*) but also with achieving driver behaviour which results in choices of speed that are appropriate in the prevailing circumstances (to discourage or prevent *inappropriate speeds*).

Furthermore, accident prevention and casualty reduction as an objective of speed management has to be pursued with due consideration of other effects. More specifically, it is important to take into account the impacts on journey-times, vehicle operating costs, exhaust emissions and noise, and the acceptability of levels of speed to road users of all kinds and to others affected by them. All these effects of levels of speed must therefore be assessed comprehensively in the context of speed management.



## 1.2 OBJECTIVES

The objective of the project MASTER (*MANaging Speeds of Traffic on European Roads*) was to produce information that can be cited in the preparation of national and EU decisions concerning speed management and speed control equipment standards. For this purpose, the project looked for answers to three key questions:

- 1) What are acceptable ranges of speeds?
- 2) What are the key factors influencing drivers' choice of speed?
- 3) What are the best speed management tools and strategies?

The answer to the first question determines the primary goals of speed management by defining the target ranges of speed for different kinds of roads, environmental conditions and driving situations. Target ranges of speed should reflect the socially desired balance between the positive and negative impacts of speed, when all impacts are considered.

The answer to the second question provides the necessary information for the assessment of measures and tools, existing and potentially available, that can be applied for adoption of target ranges of speeds.

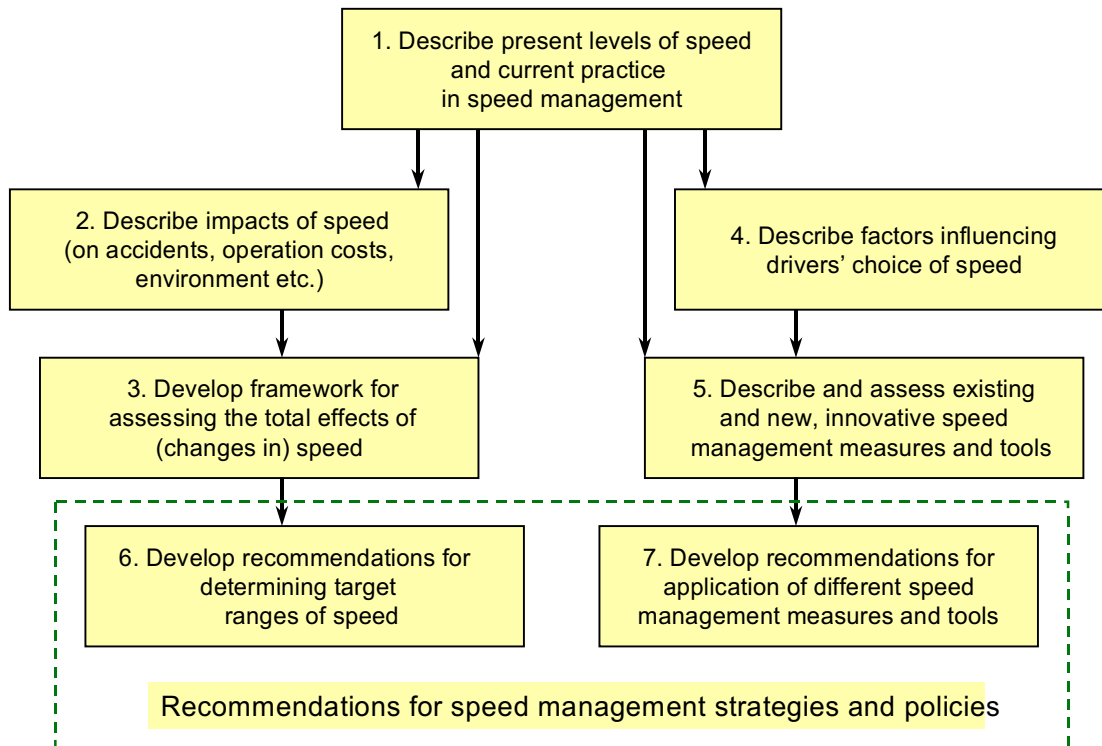
The answer to the third question builds on the answers to the other two questions and provides recommendations for practical formulation of rational speed management strategies and policies, and for application of best speed management measures and tools in different situations. This is the main objective of the project.

## 1.3 GENERAL STRUCTURE OF THE PROJECT

The general structure of project MASTER is described in Figure 1. The present levels of speeds on different kinds of roads and driving conditions, and current speed management methods and tools in different countries were the starting point of the project (box 1). From there on there were two main branches.

The branch on the left side of Figure 1 aimed for the determination of acceptable or target levels of speed on different kinds of roads and different driving conditions (box 6). The general idea of this approach was that driving speeds should reflect the desired balance of positive and negative impacts of speed from societal viewpoint, and that the process of determining target speeds should be rational, transparent and comprehensive in the sense that all impacts of speed should be considered. In order to achieve this it was necessary to describe systematically the various impacts of speed, in quantitative terms where possible (box 2). In addition, a framework was developed for simultaneous assessment of the total impact of speed (box 3). In practical applications it is usually the impacts of changes in speed of traffic that need to be assessed, rather than the impacts of absolute levels of speed.





**Figure 1. General structure of the project MASTER.**

The branch on the right side of Figure 1 aimed for the determination of speed management measures and tools that should be used in persuading drivers to adopt target ranges of speeds, taking into consideration different road, traffic and environmental conditions (box 7). The necessary building blocks came partly from research on factors affecting drivers' choice of speed (box 4), and partly from the assessment of the effectiveness, cost-effectiveness and other impacts of presently available and potential, new and innovative speed management measures and tools (box 5).

The rest of the report follows the structure of Figure 1. Phases from 1 to 5 are described in Chapters 2 to 6. Chapter 7 summarises present knowledge of speed management measures and tools. In Chapter 8 basic principles of speed management in general are outlined and recommendations for the application of various speed management measures and tools in different road categories are presented. The concluding Chapter 9 summarises the recommendations for further development of speed management, and points out related research needs.

This report is mainly based on the 12 Deliverables and 14 Working Papers from project MASTER. A brief description of their contents is provided in Appendix 1.



## 2 PRESENT SPEEDS AND SPEED MANAGEMENT METHODS IN EUROPE

By means of a questionnaire survey data collection was conducted in ten European Union countries (Austria, Denmark, Finland, Germany, Greece, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom) and ten other European countries (Hungary, Iceland, Israel, Latvia, Lithuania, Norway, Romania, Slovenia, Slovakia, and Switzerland). This survey resulted in background information on uniform and comparable data on general and local speed limits in most European countries, on speed management methods in European countries, and on actual speeds on European roads. A brief summary of the main results is presented here. More detailed results can be found in *Draskóczy & Mocsári (1997)*. A separate literature review was conducted with respect to the effects of enforcement on speed behaviour and safety (*Oei 1998*). A distinction was made between the effects of enforcement at separate locations, on specific routes, and in road networks. The objective was to give an overview of the current status of enforcement methods and to identify new ways of enhancing efficiency and effectiveness of speed enforcement measures by the police.

### 2.1 SPEED LIMITS

#### *General speed limits by road category*

In the survey a distinction was made in several road categories (built-up areas, rural roads, motor roads, and motorways) and vehicle categories (passenger cars, passenger cars towing a caravan or trailer, buses and coaches, trucks with maximum load < 7.5 tonnes, truck with maximum load > 7.5 tonnes). Table 1 presents the general speed limits of passenger cars and heavy trucks for the four road categories. In most countries the speed limits for heavy trucks also apply for buses and light trucks. Speed limits in built-up areas (BA) are in harmony with each other in most European countries (a limit of 50 km/h). Only Czech, Poland, Romania, Slovakia, and Slovenia have a limit of 60 km/h in built-up areas. On rural roads with mixed traffic (RR) the speed limits differ much more ranging from 70 up to 113 km/h for passenger cars. A limit of 80 km/h is most common for both passenger cars and trucks. Some countries apply different limits dependant on factors such as summer- or wintertime, with or without ABS brake systems, or road quality. The category motor road (MR) with access limited to motor vehicles (mostly excluding agricultural vehicles and mopeds) is not that common in Europe. Usually, speed limits are between the limits that apply on rural roads and motorways for passenger cars, a common value being 100 km/h. Motorways are the highest road category with fairly standard qualities across Europe. However, speed limits are quite diverse. Speed limits for passenger cars are mainly between 100 and 120 km/h, except for Germany where no limit exists in large parts of the motorway network (although a lot of local speed limits are in place now). Some countries allow 130 km/h, whereas some other countries have limits of 90 or 80 km/h.



**Table 1. General speed limits (km/h) of passenger cars and trucks for built-up areas (BA), rural roads with mixed traffic (RR), motor roads (only access for motor vehicles) (MR), and motorways (MW) in European countries (after Draskóczy & Mocsári 1997).**

Country	Passenger cars				Trucks			
	BA	RR	MR	MW	BA	RR	MR	MW
Austria	50	100	-	130	50	70	70	80
Belgium	50	90	90/120	120	50	60	90	90
Denmark	50	80	80	110	50	70	80	70
Finland	50	100/80	100	80/100/ 120	50	80	80	80
France	50	50/80/90	50/100/ 110	50/110/ 130	50	50/80/80	50/80/80	50/90/90
Germany	50	100	100	no limit	50	80	80	80
Greece	50	90	110	120	50	80	80	80
Ireland	48	96	-	113	48	80	-	96
Italy	50	90	90	130	50	70	70	80
Luxemburg	50	90	90	120	50	75	75	90
Netherlands	50	80	100	120	50	80	80	80
Portugal	50	90/80	100/90	120/110	50	70	80	90
Spain	50	90/100	100	120	50	70/80	80	90
Sweden	50	70/90	90/110	90/110	50	70	90	90
UK	48	96/113	-	113	48	64/80	-	96
Czech	60	90	90	130	50	80	80	80
Hungary	50	80	100	120	50	70	70	80
Iceland	50	90	90	-	50	80	80	-
Israel	50	80	90	100	50	80	90	100
Latvia	50	90	-	-	50	80	-	-
Lithuania	50	90	90	110	50	70	70	100
Norway	50	80	80/90	90	50	80	80	80
Poland	60	90	90	110	50	70	70	70
Romania	60	80	80	80	40	50	50	50
Slovakia	60	90	90	130	60	90	90	80
Slovenia	60	80	100	120	60	70	70	70
Switzerland	50	80	100	120	50	60	80	100



### *Local speed limits at specific places*

In most European countries local speed limits lower than the 50 km/h general limit are used in urban areas at specific places, such as residential areas, school areas, and traffic calming zones with values ranging between 6 and 40 km/h. Common practice is to have speed limits of 60-70 km/h at main arterial roads, sometimes even 80 km/h, depending on the quality of the road and the characteristics of the surrounding area.

## **2.2 ACTUAL SPEED LEVELS**

In many European countries, actual speeds are measured systematically by different kinds of equipment such as doppler radar, laser radar, inductive loops, pneumatic tubes, or weigh-in-motion techniques. However, results usually are not published or easily accessible. Moreover, usually no or only very limited speed data are available for different road surface, weather, visibility, or traffic density conditions. Moreover, speed indicators vary largely from mean speed, standard deviation of speed, 15th, 50th, to 85th percentiles of speed distributions. Although comparison of actual speed levels in different European countries is difficult because of these reasons, it can be concluded that speeding is a very common phenomenon all over Europe with percentages of speeding up to 80%. It is clear that speed limits themselves are insufficient for managing speeds at a desired level, even if substantial enforcement is conducted. Speeding is especially occurring on low speed urban roads and on motorways. Data from Hungary indicate that a reduction of the speed limit in urban areas from 60 to 50 km/h in 1993, only had a temporary reducing effect on actual speeds. Results of systematic speed measurements indicate that actual speeds are in a high percentage over the speed limit and the speed level has been permanently increasing during the last decades in Europe. It means that speeding is becoming a more and more frequent problem all over Europe.

## **2.3 SPEED MANAGEMENT METHODS**

Speed limits are the backbone of speed management in Europe. Speed is limited on all roads except for some sections of German motorways. Furthermore, compliance to speed limits is enforced by the police in all countries, although there are differences in the intensity and tolerances of the enforcement and penalties for speeding. Police enforcement typically uses conventional methods where police officers measure the speeds by radar or other portable device, stop the speeders and prescribe fines at the site. Recently, the use of speed cameras has increased. In some countries the owner of the vehicle can be held responsible for speeding offences and identification of the licence number of the speeding vehicle is enough, whereas in other countries the driver needs to be identified from the photo. The former system requires less manual work and is therefore much more cost-effective than the latter.

In all countries lorries have a vehicle type specific speed limit that varies between 70 and 100 km/h. Novice drivers may also have a specific speed limit of similar magnitude.



Local, reduced speed limits are often used in the vicinity of schools and dangerous intersections, for example. Variable speed limits are used to some degree, usually on motorways or other high volume roads, where speed limits are typically reduced during rush hours and in adverse road surface and weather conditions.

Speed recommendations displayed by fixed roadside signs are used to some degree in many countries, especially in sub-standard curves. Recommended speed is lower than the speed limit.

Information campaigns about the dangers of speeding and publicity for the use of appropriate speeds are part of speed management in many countries.

Physical measures are used for speed management in increasing numbers in urban areas. Measures like speed humps, chicanes and road narrowings are used especially in residential areas. Roundabouts can also serve speed management and they are widely used in some countries whilst they are rare in others. Speed reduction is often one of the main objectives of traffic calming, where entire roads or areas are treated using combinations of measures mentioned above, and other measures like surface treatments or road markings, village gateways, raised pedestrian crossings or junctions, re-routing of traffic and information campaigns. Traffic calming methods have been widely used in some countries (e.g. the Netherlands), but in most countries only to a limited degree.

In rural areas rumble strips at approaches to intersections are perhaps the most common physical speed management tool. Because of higher speeds and the danger that physical speed-reducing measures can cause accidents, they are seldom used on main rural roads. Quite the contrary, there is often a tendency to make rural roads straight and wide and keep the roadsides open and clear, because all deviations from the highest standard potentially increase accident risk. This is not necessarily an ideal solution since high geometric standard in general increases speeds, which in turn increases the number and severity of accidents.

From an administrative point of view the responsibility for speed management is typically divided between several authorities, e.g. central government, national and local road administrators, the police and traffic safety organisations. The roles of the European Community and vehicle manufacturers have been rather minimal in this respect so far. Even though there is co-operation between authorities and guidelines for road design, for example, speed management can largely be seen to consist of independent actions without a distinctive integrated long-term plan. This is the case especially in urban areas where local authorities can have different views regarding speed management, and also big variations in the available resources may exist.



### 3 IMPACTS OF SPEED

The rapid door-to-door journey times made possible by motor vehicles and the road system are one of the great benefits conferred by modern transport. But the levels of speed that make these journey-times possible also have effects in terms of operating costs, noise, exhaust emissions and the occurrence of traffic accidents and consequent death, injury and material damage. Where motor traffic shares the road with vulnerable road users or travels close to people's homes, issues of acceptability of levels of speed to vulnerable road users and to residents arise. Nor are current levels of speed necessarily acceptable to all of the drivers who participate in them.

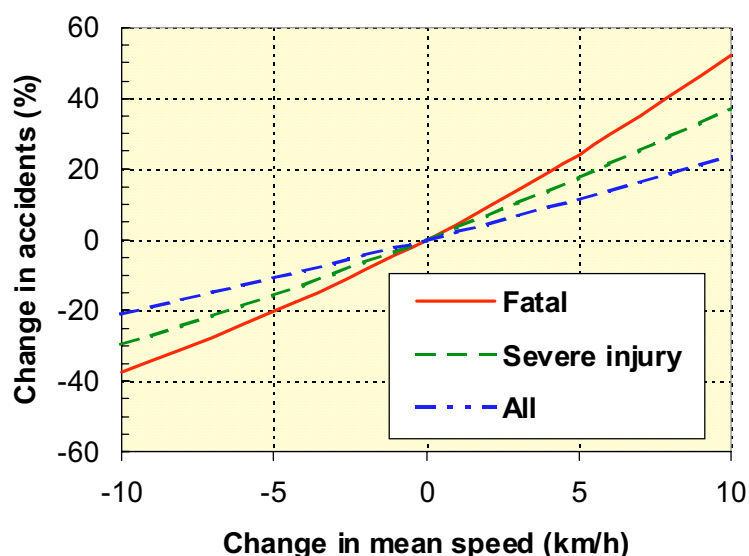
The project MASTER arose primarily from concerns about the contribution of speed to road safety, as expressed, for example, by the *ETSC (1994)*, and reiterated more recently by the *CEC (1997)* and the *European Parliament (1998)*. But accident prevention and casualty reduction as an objective of speed management has to be pursued with due consideration for the value to individuals and society of rapid journey-times, the consequences of levels of speed for operating costs, emissions and noise, and the acceptability of levels of speed to road users of all kinds and to others affected by them. All these effects of levels of speed must therefore be assessed comprehensively in the context of speed management.

Chapter 3 gives an overview of the various impacts of speed.

#### 3.1 ACCIDENTS

##### 3.1.1 Previous studies

Early studies on the relationship between speed and accident involvement showed that vehicles travelling more slowly than the average speed for the road, as well as those travelling faster, had an above-average risk of accident involvement, but that the severity of accidents increased more than proportionally to speed. These early findings are consistent with subsequent findings that, on roads of a given type, injury accident rate, severe injury (including fatal) accident rate and fatal accident rate increase roughly as the 2nd, 3rd and 4th powers of the mean traffic speed as illustrated in Figure 2 (*Andersson & Nilsson 1997*). Other studies summarising reported findings (mainly from before-and-after studies) are generally in agreement with the Swedish model (*Elvik et al. 1989, 1997, Finch et al. 1994, Ranta & Kallberg 1996*). All these studies are in line with a rule of thumb stating that a reduction of 2 to 3 per cent in injury accidents results from a 1 km/h reduction in mean speed. This rule is applicable when the reduction in mean speed is less than about 10 km/h. Accident costs increase with speed approximately twice as fast as the number of injury accidents (*Kallberg 1998*).

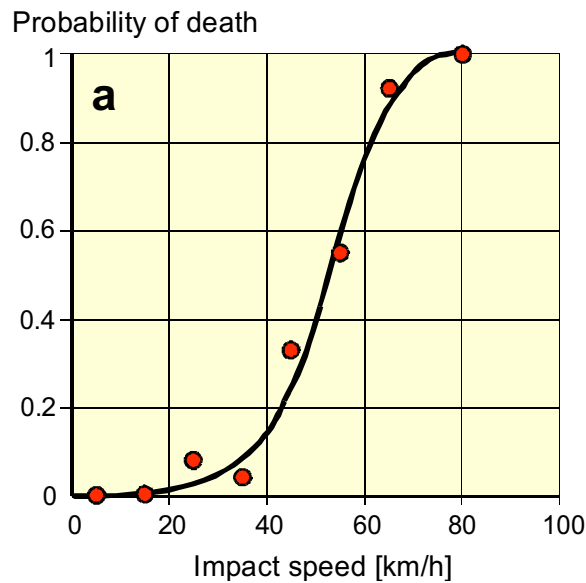


**Figure 2.** Effects of mean speed on the number of accidents according to the Swedish model in case where the initial mean speed is 80 km/h (Andersson & Nilsson 1997).

Accident rates and the variance of speed are positively correlated (Garber & Gardirau 1988, Finch et al. 1994, O’Cinnéide & Murphy 1994). It has even been claimed that speed variance, and not the absolute level of speed is the most important speed-related factor contributing to accidents (Lave 1985). Such claims, however, are contrary to common sense because in many common accident types (e.g. single vehicle accidents and head-on accidents) there is no logical connection between speed variation and accident causation. Furthermore, speed variation does not affect the consequences given that an accident occurs. An increase in the absolute speed, on the other hand, logically increases accident risk because it decreases the time the driver has in critical situations for observation, decision-making and evasive manoeuvres.

Importantly, increases in the absolute speed (unlike increases in speed variation) practically always increase the forces affecting in the crash. Consequently, increases in speed increase the damages to the vehicles and the severity of injuries to the occupants. Furthermore, in pedestrian accidents the fatality risk of the pedestrian increases rapidly with the impact speed of the car (e.g. by a factor of 2.5 when impact speed increases from 40 to 50 km/h) (Figure 3).

Apparently contradictory indications in some studies (e.g. Garber and Gardirau 1988) that accident rate was negatively correlated with mean speed can often be accounted for by failure to allow for differences in geometric characteristics between the roads that had been studied.



*Figure 3. The effect of impact speed on fatality risk in pedestrians accidents (Pasanen 1991).*

### 3.1.2 Methodological issues

A major part of the results cited above have been derived from before-and-after studies of changes in speed limits. A complementary approach to that of before-and-after analysis is the cross-sectional analysis of speed and traffic accidents. Investigations of speed-accident relationships by means of cross-sectional analysis of data for samples of stretches of road need to take into account traffic flow, geometrical characteristics and the variability of speeds as well as mean speed. Multiplicative models seem to be most appropriate for cross-sectional analysis (*Allsop 1998, Baruya 1997, 1998c*).

The evidence of causality in relationships derived from before-and-after analysis is stronger than in those derived from cross-sectional analysis. However, the opportunities for the former are fewer, the time scale for gathering the data for them is longer, and the scope for obtaining representative samples of sites with given characteristics is smaller, than for the latter. Several investigations of speed-accident relationships in recent years have therefore been based on cross-sectional analysis (*Allsop 1998, Baruya 1997, 1998c*).

### 3.1.3 Statistical modelling for single-carriageway rural roads

#### *Models for England*

Speed, flow and 5 years' accident data were analysed for 78 stretches of rural single-carriageway road in various counties in England (*Baruya 1998a, 1998c*). Limited geometric data was extracted from maps. Additional geometric data gathered on site was available for a subset of the roads. On 74 of the roads the speed limit was 60 miles/h (97





km/h) and on the other 4 it was 50 miles/h (80km/h). The distribution of speeds of vehicles on each road was characterised by three parameters:

- the mean speed,
- the proportion exceeding the speed limit, and
- the proportion travelling at less than half the speed limit.

The second and third parameters can be seen as indicators of the levels of speeding and congestion, respectively, or simply as indicators of the sizes of the upper and lower tails of the distribution.

Mean speed was found to be a decreasing function of flow and, for given flow, to be strongly correlated positively with the speed limit itself and with the percentage exceeding the speed limit, and negatively with the percentage travelling at less than half the limit. This means that in the modelling of the speed-accident relationships and interpretation of the resulting models, effects of changes in mean speed cannot meaningfully be considered without due regard to the likely concomitant changes in the distribution of speeds as characterised by the other two parameters (*Baruya 1998a, 1998c, Allsop 1998*).

Accidents included in the analysis were reported personal injury accidents within the stretches of road, including those at minor junctions and private accesses, but excluding those at major junctions at ends of the sample sections. Numbers of accidents per year were estimated to be proportional to

- mean speed in km/h to the power -5.95
- percentage exceeding the speed limit to the power 0.227, and
- percentage below half the speed limit to the power -0.383,

with a constant of proportionality estimated in terms of amount of traffic, length of the stretch of the road, and number of junctions. The fit was modest, accounting for only 36 per cent of the non-Poisson variation in the accident numbers per year. Details of the models for mean speed and number of accidents are given in Appendix 2.

The models give rise to a number of questions, the most obvious of which is the implication of the sizeable negative power of mean speed in the model for numbers of accidents per year. There is a *prima facie* inference that accidents decrease with increasing speed, which would be counter to so much previous evidence and to physical and behavioural understanding. But this inference is negated by the evidence from the model for mean speed of a strong interdependence between mean speed and the other parameters of the speed distribution. This means that speed cannot realistically be varied in the accident model without making corresponding changes in the percentages above the limit and below half the limit in accordance with the model for mean speed (*Baruya 1998a, 1998c, Allsop 1998*).

This can be illustrated by considering a 5km stretch of road without junctions, with a speed limit of 100km/h and a flow of 7500 vehicles/day. Table 2 shows for percentages



exceeding the speed limit ranging from 1 to 20 what percentages below half the speed limit are consistent, according to the model for mean speed, with mean speeds of 90km/h and 85km/h, together with the corresponding estimated numbers of accidents per year. In every case, fewer accidents per year are estimated to occur at the lower speed, but the difference is much smaller than would be expected from the rule of thumb based on before-and-after studies. This discrepancy is addressed later in this section, but the sign and size of the power of mean speed in the model remain a source of concern. The lack of variation in estimated accident numbers as the percentage exceeding the speed limit changes is accounted for by the countervailing change in the percentage under half the speed limit that is required to keep the mean speeds at their chosen levels (*Baruya 1998a, 1998c, Allsop 1998*).

**Table 2. Estimated numbers of injury accidents/year on a 5km length of rural single-carriageway road in England with speed limit of 100km/h and flow of 7500 vehicles/day when the mean speed is 90 or 85km/h and the percentage exceeding the speed limit ranges from 1 to 20 (Allsop 1998).**

Percentage exceeding the speed limit:	Percentage under half the speed limit with mean speed:		Estimated number of injury accidents per year with mean speed:	
	90km/h	85km/h	90km/h	85km/h
1	0.076	0.186	1.801	1.794
5	0.196	0.480	1.804	1.797
10	0.295	0.723	1.805	1.798
15	0.374	0.918	1.805	1.799
20	0.444	1.088	1.806	1.799

A second question arises from the fact that the models are being considered here in the context of speed management. This is whether it is appropriate for the distribution of speeds to be described by parameters that are defined in relation to the speed limit, which is itself one of the management tools that need to be assessed. It would be preferable to use parameters inherent in the speed distribution, like the coefficient of variation (standard deviation of speeds divided by mean speed).

A third question is the strength of effect of the speed limit itself upon the mean speed as estimated by the model for the latter. As Baruya has pointed out (*1998c*), this is greater by a factor of about 2 than has typically been found in practice. However, this estimate of the effect of speed limit is based on data for just 4 stretches of road with a limit of 50 miles/h out of a sample of 78 in which the other 74 had a limit of 60 miles/h. Thus, although the relevant parameter was more than 4 times its standard error of estimate, it is clearly possible that a larger sample would give an appreciably different estimate. It is therefore advisable to confine the application of these models to roads with a speed limit of 100 km/h, as is done in the foregoing example.



A fourth question is whether if fuller data about road geometry had been available, relevant geometric parameters would have been significant in the fitted models. This would be relevant to the use of the models to estimate the likely effects of changes in road geometry being considered for purposes of speed management.

The last two questions reflect the fact that these models are the result of an exercise in data gathering and model development that was tightly constrained by the strict limitation imposed by the overall budget for MASTER. This being so, the resulting models must be regarded as preliminary, and a full-scale data-collection and modelling exercise would enable the foregoing questions to be addressed with a good prospect of their being resolved. Nevertheless, the models resulting from the work summarised in this section provided the basis for useful work with data from other Member States (*Allsop 1998*).

### **Models for the Netherlands, Portugal, Sweden and UK**

The models described in Section 3.1.3.1 were applied to on 28 stretches of single-carriageway rural roads in The Netherlands, 39 in Portugal, 73 in Sweden and 61 in the UK (*Baruya 1998b, Baruya 1998c*). Data available of these road sections comprised information about speed, flow, geometry and injury accidents. Speed limits on these roads varied from 70 to 110 km/h.

Mean speed was found to be estimated in terms of speed limit, percentages above the limit and below half the limit, and traffic flow. The model parameter values were consistent with those estimated from the English data alone, with the addition of a multiplier comprising road length raised to a small power. Details of this model are given in Appendix 2.

When the above described UK model for number of injury accidents per year was applied directly to data from the other three countries, it overestimated accident frequencies for The Netherlands and Sweden by factors of 1.7 and 1.9 respectively, and underestimated those for Portugal by a factor of 4.5.

The model was first refined by fitting to data from England, The Netherlands and Sweden, using the same variables as for the previous fitting to the English data, except that road width was listed as an additional variable. Number of accidents per year was estimated to be proportional to

- mean speed in km/h to the power -2.492,
- percentage exceeding the speed limit to the power 0.114, and
- $\exp(0.023 \times \text{speed limit})$

with a constant of proportionality estimated in terms of the amount of traffic, length of the stretch of road, number of junctions and road width. Details of this model are given in Appendix 2. Compared to the model based on the English data only, in this model:



- percentage below half the speed limit does not appear in the model,
- speed limit does appear (on the basis of data for a range of values), and
- the power of mean speed is more than halved (though it remains negative).

This model accounts for 75 per cent of the non-Poisson variation in the accident numbers per year, and was found to fit the data for all 3 countries well, but still to underestimate the number of accidents per year on the Portuguese roads by a factor of 2.7.

From this model and the 4-country model for mean speed it can be estimated that *for changes in mean speed resulting simply from an increase in driving above the limit*, the elasticity of number of injury accidents with respect to mean speed is about 1.5.

These two models can also be used, as in the case of Table 2, to estimate for percentages exceeding the speed limit what percentages below half the speed limit are consistent, according to the model for mean speed, with particular mean speeds, together with the corresponding estimated numbers of accidents per year. Now that the effect of speed limit appears in both models and is estimated from data for a range of limits, the effect of a difference in speed limits can be included. The accident model also now requires the width of the road to be specified. The results of such a calculation are shown in Table 3.

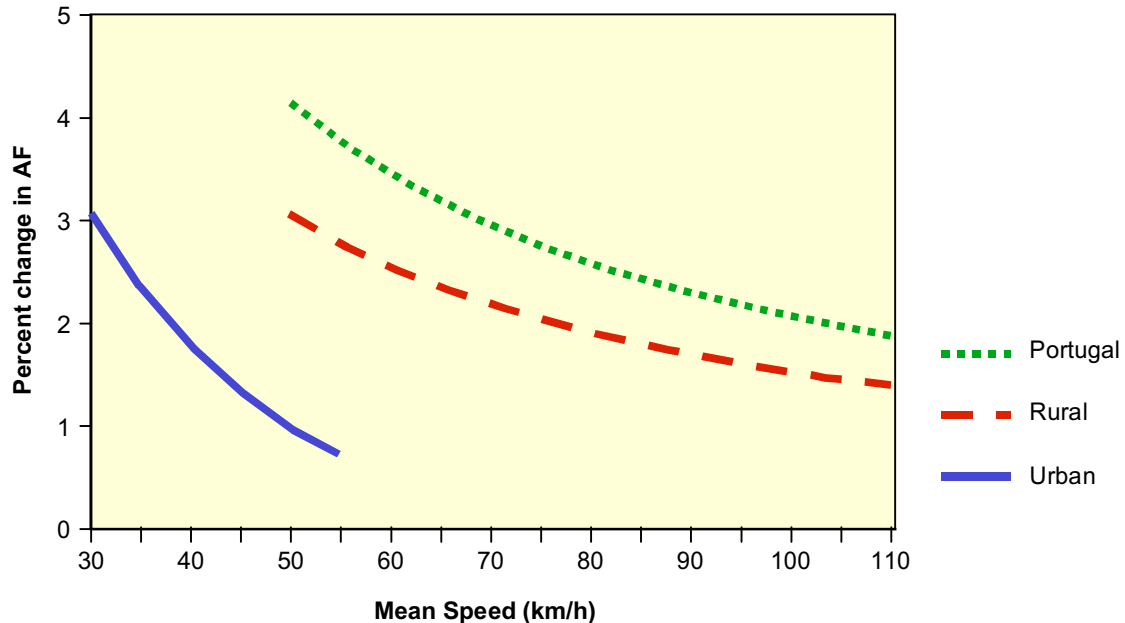
**Table 3. Estimated numbers of injury accidents/year on a 5 km length of rural single-carriageway road 8 m wide in England, The Netherlands or Sweden with a flow of 7500 vehicles/day when the mean speed is 90 km with a speed limit of 100 km/h or 85 km/h with a speed limit of 90 km/h and the percentage exceeding the speed limit ranges from 1 to 20 (Allsop 1998).**

Percentage exceeding the speed limit:	Percentage under half the speed limit with mean speed:		Estimated number of injury accidents per year with mean speed:	
	90km/h	85km/h	90km/h	85km/h
1	0.0007	0.0003	1.520	1.392
5	0.027	0.011	1.826	1.673
10	0.132	0.051	1.976	1.810
15	0.332	0.129	2.070	1.896
20	0.640	0.249	2.139	1.959

It can be seen in this case that the models estimate an increase of about 9 per cent in the number of injury accidents corresponding to a 5 km/h increase in mean speed from 85 to 90 km/h. This is in line with the Swedish model, which predicts that such increase in the this mean would increase the number of injury accidents by  $(90/85)^2 - 1 = 12$  per cent. The predicted increase according to the rule of thumb is 10 to 15 per cent. Consequently, all these predictions are of a similar order of magnitude.



The results from the present study are also in line with the Swedish model in the sense that the percentage change in the number of injury accidents resulting from a 1 km/h in mean speed is the higher the higher is the initial speed ( Figure 4).



**Figure 4. Percent change in accident frequency for 1 km/h change in mean speed (Baruya 1998c). The curve for urban roads is from a previous UK study (Baruya & Finch, 1994).**

For the Portuguese roads, it was found that with the exception of two roads with unusually high accident frequencies, the number of accidents per year could be roughly estimated by applying the model fitted to data from the other three countries and raising the resulting estimate to the power 1.35. Reasons for this difference remain to be investigated.

A by-product of the analysis of data from the four countries was a finding that the sampled stretches of road could be classified in terms of traffic flow, road width and parameters of the speed distribution into 4 groups:

- congested roads with high flow and low speeds
- narrower roads with moderate flow and a wide range of speeds
- uncongested roads with low flow and many excess speeds
- wide roads with moderate flow and high speeds

Taken together with appropriate consideration of the surroundings, layout, and traffic and other functions of the road, and subject to a definition of *congested* that takes account of variation of traffic flow over the day, this classification might perhaps contribute to a trans-national categorisation of rural single-carriageway roads independent of national administrative classifications.



### 3.1.4 Conclusions

Work within MASTER on speed-accident relationships, though only preliminary in scale and confined to one important category of roads, single-carriageway rural roads, has demonstrated that cross-sectional log-linear statistical modelling offers the prospect of cross-national models that could estimate the effects of choice of speeds upon accident frequencies on particular categories of road in a range of Member States (*Allsop 1998*).

Development of this tool to contribute to the appraisal of effects of different levels of speed on different types of road requires a full-scale programme of development of cross-national models for each relevant category of road - notably motorways, main rural roads and main urban roads. Such a programme should recognise that

- full-scale model development requires extensive collection of high-quality speed, flow and geometric data according to a strict experimental design from appropriately selected stretches of road in a range of Member States;
- the design of the full-scale work may usefully be informed by smaller focussed studies to explore particular aspects of the modelling;
- speed should be represented in the models not simply by the mean or median speed but by a range of parameters of the distribution of speeds, and these parameters should be determined from the observed speeds themselves without reference to the speed limit;
- the speed limit itself is a separate candidate variable for inclusion in the models;
- models which are cross-national in respect of many parameters will probably also need to include some nationally or even regionally specific parameters; and
- development of the models should include extensive cross-checking for consistency with the available results of before-and-after analysis of the effects of changes in speed on accident occurrence.

Application of the resulting models and further models of this type will require mutually consistent adjustment of all speed-related variables to reflect the actual nature of changes in speed levels that are being appraised; oversimplistic interpretation of individual parameters will need to be guarded against. Use of the models in practice should then be accompanied by a programme of before-and-after studies to monitor their continuing validity (*Baruya 1998c, Allsop 1998*).

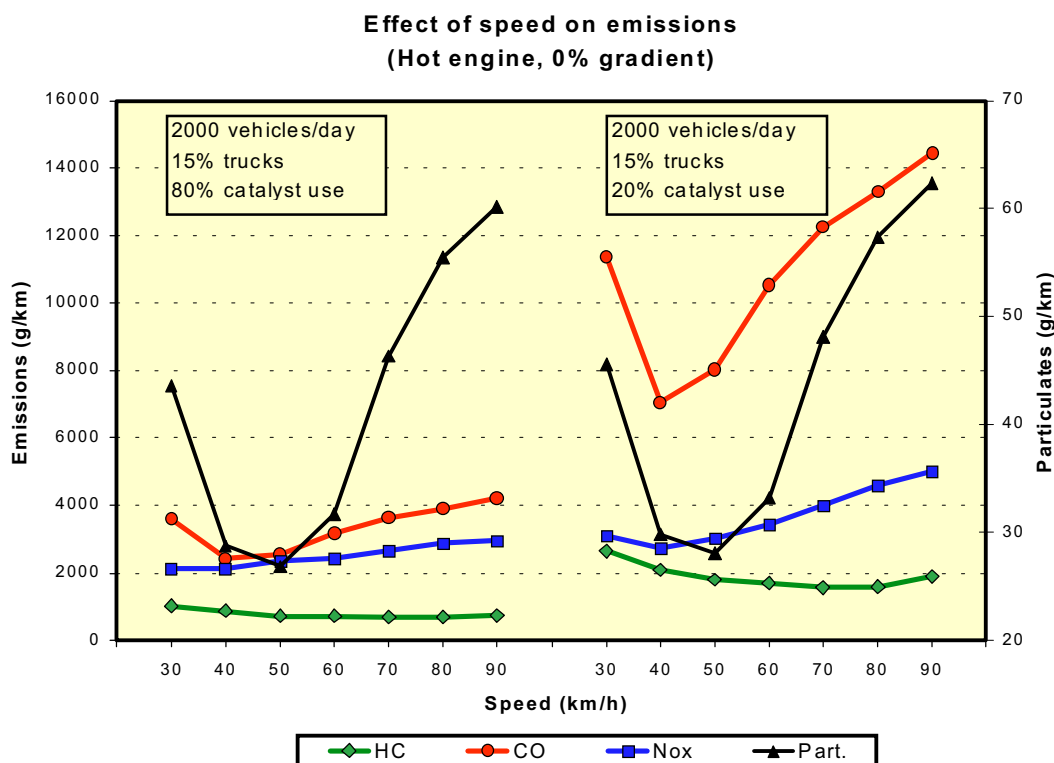


### 3.2 EXHAUST EMISSIONS

Emissions from road transport consist of a variety of pollutants which are produced in different quantities at different speeds. The review by *Robertson et al. (1998)* summarise the impacts of speed on exhaust emissions.

The review begins by describing the processes by which emissions from motor vehicles are produced. Since this part of the review is only indirectly connected to the impacts of speed it is not considered here any further, but the interested reader is referred to *Robertson et al. (1998)* and to the earlier work by (*Haywood 1988*).

The major pollutants are carbon monoxide (CO), oxides of nitrogen (NO<sub>x</sub>), hydrocarbons (HC) and particulate matter. In general the HC emissions decrease with speed and NO<sub>x</sub> emissions increase with speed. CO and particulates have their lowest emission levels at medium speeds (Figure 5). Carbon dioxide (CO<sub>2</sub>) emissions are proportional to the amount of fuel consumed.



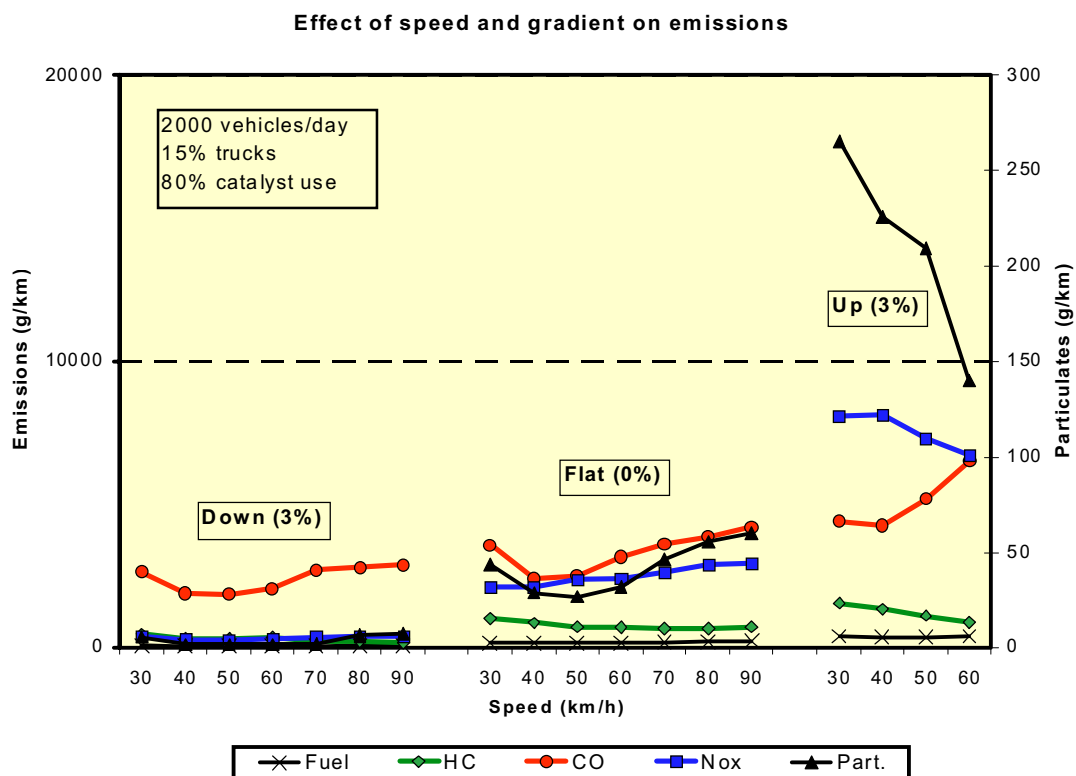
*Figure 5. Effect of speed on emissions (Robertson et al. 1998).*

The curves presented in Figure 5 are based on a microscopic model developed specifically to provide estimates of vehicle emissions under various relatively free-flowing traffic conditions is the model VETO (*Hammarström and Karlsson 1987*). This particular application of VETO demonstrates how the estimated levels of emissions vary



with speed for a stream of vehicles consisting of 85 per cent cars, 10 per cent heavy lorries and 5 per cent medium lorries at steady speeds of between 30 and 90 km/h and level ground. Separate estimates are made for the cases in which 20 per cent and 80 per cent respectively of cars were assumed to be fitted with catalytic converters. *Robertson et al. (1998)* provide a number of tables where the dependence of emissions on speed has been calculated for different traffic volumes (2000, 8000 and 15000 vehicles per day), gradients (from 10% downhill to 3% uphill), proportions of cars with catalytic converters (20% or 80%).

Gradient has a strong effect on fuel use and strongly differentiated effects on the various emissions (Figure 6).



**Figure 6. Emissions as a function of speed and gradient (Robertson et al. 1998).**

Changes in speed, such as occur in transitional zones and near to localised speed-reducing measures, can make a large contribution to emissions and in particular hard acceleration can cause a disproportionate amount of pollutants to be emitted. Accelerating vehicles in the above mentioned mix of traffic by 10 km/h on the level uses of the order of 10 per cent of the fuel used in travelling 1 km at steady speed. The corresponding percentages for emissions range from about 5 for HC to about 30 for particulates. All these percentages are dependent upon the initial speed from which the acceleration takes place. Decelerating this mix of vehicles by 10 km/h on the level results in much smaller reductions in fuel use and emissions, except that at low speeds deceleration can result in small additional emissions of CO (*Robertson et al. 1998*).





Emissions are greatly increased when engine and catalytic converter are cold. This has implications for speed management policies, which require the choice of low speeds for relatively long distances in urban areas.

A range of models and data have been identified from which a systematic basis for estimation of effects upon emissions of speed management measures and policies could be developed, but effort will be needed to exploit these sources fully (*Allsop 1998*, *Robertson et al. 1998*).

The relevance to appraisal of speed management measures of previous studies of the environmental effects of traffic management schemes is identified, and an internationally wide-ranging review of assessments of these (*Abbott et al. 1995*) is identified. Counterpart studies of effects of schemes on interurban roads are exemplified by a study by *Metz et al. (1997)* of a scheme on a German Autobahn.

Some microscopic and mesoscopic traffic simulation models can be used to provide estimates of effects of traffic management schemes on emissions, and details of those which claim this capability are summarised by *Robertson et al. (1998)*.

The modelling can be extended to the more realistic case of given flows of mixtures of vehicles with different desired speeds travelling on a given stretch of road. The VETO model (*Hammarström & Karlsson 1987*) is a microsimulation model that takes into account the accelerations and decelerations associated with overtaking and with waiting for opportunities to do so.

Two databases concerning emissions were identified. CORINAIR (*Eggleston et al. 1989*), was developed to provide an EU-wide inventory of pollutant sources by Member State in 1990 and has since been updated. It includes estimates of emissions at a set speed for certain types of vehicle and road, together with curves estimating speed-dependence.

MODEM takes the form of a computer program (*Barlow 1995*) incorporating data resulting from a study (*Jost et al. 1992*) in which 150 vehicles from a range of European passenger cars were used to measure emissions in the laboratory. The data was derived from a set of realistic driving cycles based on on-street measurements made with instrumented cars in 6 cities in Britain, France and Germany.

There thus exist a range of models and data from which a systematic basis for estimation of effects upon emissions of speed management measures and policies could be developed, but effort will be needed to exploit these sources fully.

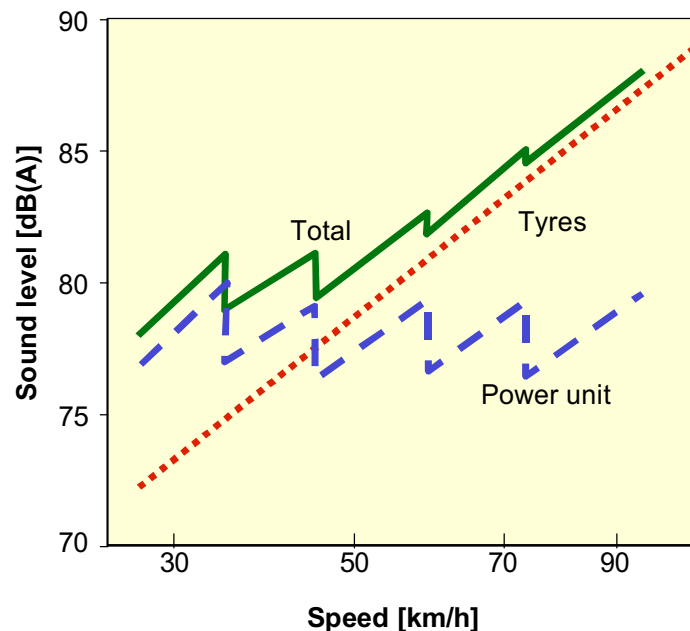
### 3.3 NOISE AND VIBRATION

Methods of quantifying levels of noise are summarised by *Robertson et al. (1998)*. It is recognised that the measure most widely used in the EU for specifying the level of noise from road traffic is the energy-equivalent level  $L_{eq}$ . This is the level of continuous steady



sound, which has the same energy content per unit time as the average over time for the continually fluctuating traffic noise being quantified. The normal unit of measurement is the A-weighted decibel (dB(A)) in which the intensities of sound of different frequencies are weighted in proportion to the typical human response to them, which is in turn, for any given frequency, proportional to the logarithm of the energy-intensity of the sound.

Traffic noise arises from two main sources: the power units of vehicles and tyre-road interaction. Noise from the latter dominates at higher speeds - above the range 20-40 km/h for new cars and above 30-60 km/h for new lorries - because tyre-road noise increases strongly with speed, typically by 12 dB(A) for a doubling of speed (Figure 7). For older vehicles the speeds above which tyre-road noise dominates are about 10 km/h higher, because power unit noise has been progressively reduced by developments in technology.



**Figure 7. Generalised noise-speed relation (Robertson et al. 1998).**

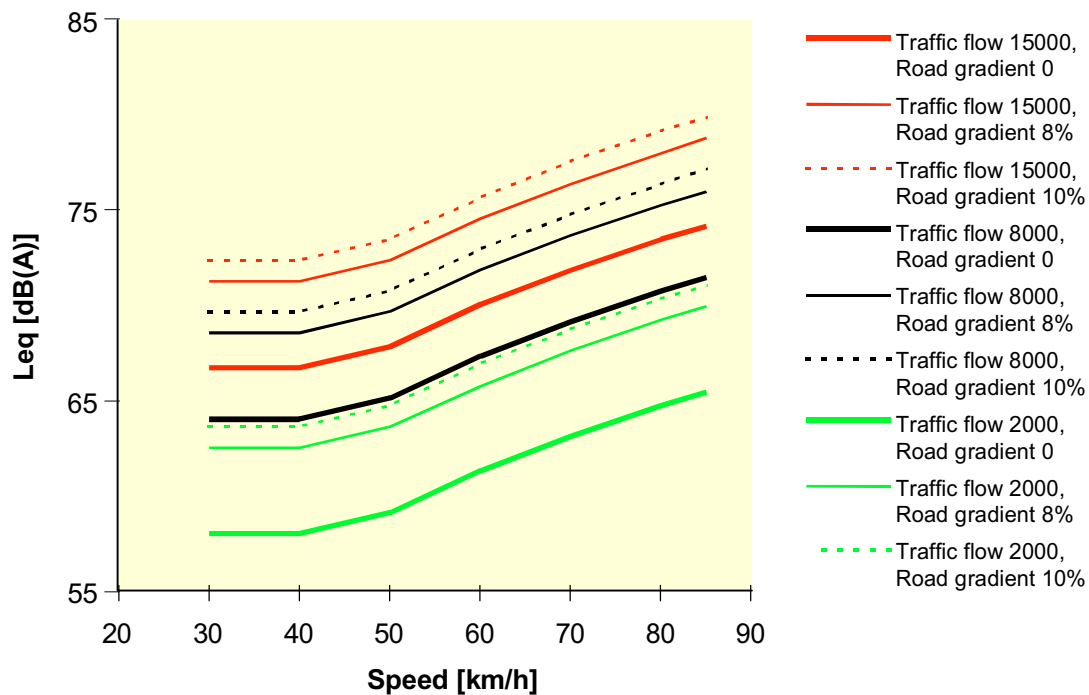
The maximum level of tyre-road noise in dB(A) experienced by a bystander as a vehicle passes is related approximately linearly to the logarithm of the vehicle speed in km/h, with a coefficient typically about 33. Having regard to the definition of the decibel, this implies that the maximum energy-intensity of the tyre-road noise from a passing vehicle is typically proportional to speed to the power 3.3. Swedish evidence is that this power ranges in practice from about 2.7 to 4.0 (Nelson 1987). The duration of the noise is inversely proportional to the speed at which the vehicle passes. It follows that the integral of the energy-intensity of the tyre-road noise over time for the passage of a vehicle is typically proportional to the vehicle speed to the power 2.3. The energy-equivalent sound level for a given flow of similar vehicles is therefore also typically proportional to vehicle speed to the power 2.3. When variability between vehicles, which is greater at lower than at higher speeds, is taken into account, however, the



dependencies of maximum noise level and energy equivalent noise level upon speed are found to be quite similar (*TemaNord 1996*).

Many European countries have established road traffic noise prediction models and a recent comparison of seven of them (*Van Leeuwen et al. 1996*) has shown that they are consistent to within 2 or 3 dB(A) in representing the dependence of vehicle noise upon speed. The more recently developed or updated models are likely to be more accurate in this respect because of the recent tendency for the less speed-dependent power unit noise to decrease relative to the more speed-dependent tyre-road noise.

One of the most recent models is the Nordic model produced by *TemaNord (1996)* and made operational in software produced by *Trivector (1996)*. This is used by *Robertson et al. (1998)* to calculate examples of the estimated speed-dependence of A-weighted  $L_{eq}$  over the range 30-90 km/h at a specified position relative to roads with different gradients carrying a given mix of traffic at different levels of flow. In all cases the value of  $L_{eq}$  is similar at 30 and 40 km/h and then rises roughly linearly and by about 7 dB(A) between about 40 and 90 km/h (Figure 8).



**Figure 8. The impact of speed on noise (Robertson et al. 1998).**

A gradient of 10 per cent is estimated to add about 5 dB(A), but the model is unable yet to estimate differences between the gradient effects at different speeds.

Effects of acceleration and deceleration on noise are typically modest at speeds over 50 km/h but higher at speeds lower than this. This has implications for the use of intermittent speed-reducing devices such as road humps or chicanes. Specially textured



surfaces and surface wetness can affect the level of noise, but variations of these effects with speed are modest.

Speed can affect the distance over which noise travels to the extent that the frequency spectrum of the noise is altered by changes in speed, because the lower frequency components travel further.

Vibration in buildings can be caused by road traffic either through low-frequency noise causing resonance in components of buildings, or through bouncing of the wheels of heavy vehicles causing ground vibration. Findings on the dependence of vibration on traffic speed were not located.

### **3.4 COSTS TO USERS OF VEHICLES**

#### **3.4.1 Overview**

Speed management influences the speeds at which vehicles are driven on various kinds of roads in the course of their journeys. This in turn affects the users of the vehicles by changing

- the time spent on the journey;
- the amount of fuel used;
- the amount of oil used;
- the amount of wear on the tyres;
- the cost of maintaining the vehicles; and
- the rate of depreciation of the vehicles.

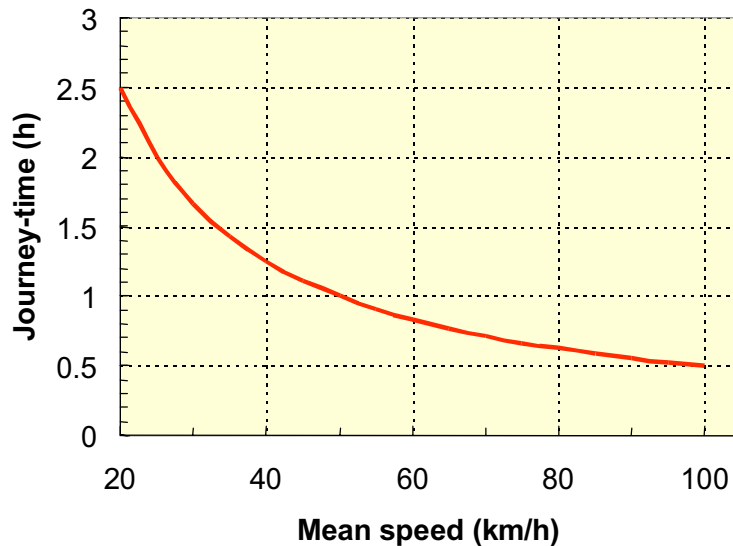
These are changes in the costs incurred by users of the vehicles. Some changes may be quite accurately perceived by the users in terms of time and money; other changes may be appreciably or even substantially misperceived. Misperception does not affect the incidence of the changes in cost, but does affect the users' response to the changes. Someone who notices that a journey takes longer or costs more may seek to modify their travel to mitigate the increases in cost, whereas no such response is likely if the changes in cost are not noticed, or not associated with the journey from which they arise (*Allsop 1998*).

Nor do changes in costs to users imply equal changes in cost as reckoned by governments from the point of view of society. The element of taxation in prices paid for the use of vehicles is a cost to the user but not to society, which gains if people spend more on highly taxed items (such as fuel for motor vehicles) and less on modestly taxed items. And governments do not in general attach the same value to people's time spent or saved as do the people themselves (*Allsop 1998*).



### 3.4.2 Time costs

Journey-time ( $h$ ) is equal to distance ( $km$ ) divided by speed ( $km/h$ ). For any (absolute) change in speed, the change in journey-time is the greater the smaller is the initial speed (Figure 9).



*Figure 9. Dependence of journey time on mean speed for a 50 km journey (Robertson & Ward 1998).*

Giving a monetary value to time costs (or savings), however, is not necessarily as simple. In practically all countries values of time are provided for different vehicle types (e.g. cars/lorries/buses), and sometimes also for different occupant categories (drivers/passengers) and separately for working and non-working time.

Whereas monetary and other material costs to vehicle users mount up in value additively whether they are incurred in a few large increments or many smaller ones, it is strongly debated whether the same is true of changes in travel time. Practice in the valuation of such changes differs in this respect among Member States. Some aggregate all changes in time, however small, and value the total, whilst others disregard changes smaller than a certain threshold (Kallberg *et al.* 1998).



### 3.4.3 Vehicle operating costs

Vehicle operating costs (VOC) describe the costs of running a vehicle. VOC may include some or all of the following components:

- Fuel
- Oil
- Tyres
- Maintenance
- Cost of time spent on maintenance
- Wear and tear on vehicle
- Value of time for vehicle operators

A number of models describing the relationship between speed and VOC are summarised by *Robertson & Ward (1998)*. They are usually based on the average speed of travel, and are most directly applicable to travel along a single road section of known characteristics. This is because they are often used in the economic appraisal of road construction schemes in which flows of traffic currently using a road section with one set of characteristics will be provided instead with a new or modified section of road having different known characteristics. VOC models may include the following factors which may affect the components:

- Speed
- Hilliness
- Bendiness
- Vehicle type
- Road type
- Road roughness
- Snow/ice
- Speed limit
- Road width

Vehicle operating cost models may be mechanistic or empirical with the mechanistic ones being based on a model of the operation of the vehicle. This may be considered to border on a simulation of vehicle operation. Examples of this type of model are the VETO (*Hammarström & Karlsson 1987*) and the New Zealand VOC model (*Bennett 1989*). This type of model is highly detailed with many variables required and can include vehicle types, road conditions and speed profiles. This type of model requires considerable amounts of detailed data.

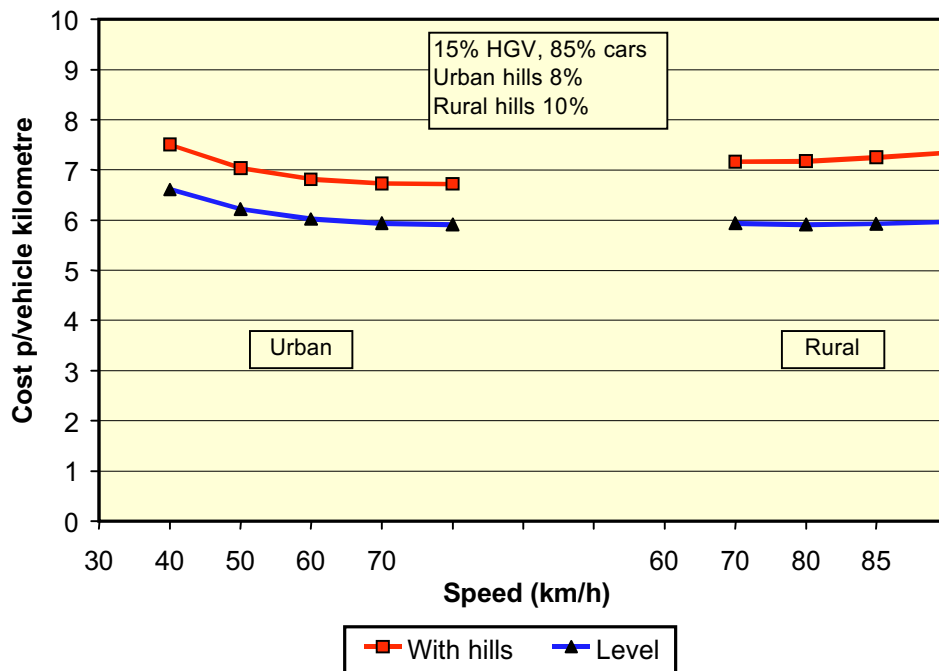
Other estimates of vehicle operating costs may be based on empirical data and may be based on simple regression models of the various components of vehicle operating costs



(for example *Department of the Environment, Transport and the Regions 1997*). These are likely to have a few vehicle classes corresponding to typical vehicles, and may include variables such as road type, gradient and bendiness.

It is not transparent how some of the vehicle operating cost models handle issues relating to congestion and vehicle interaction in streams of traffic where there are speed differentials. Moreover, VOC models have not been designed with speed management issues in mind and so have some limitations for the purposes of assessment of the effects of speed management.

An example of vehicle operating costs as a function of speed is given in Figure 10.



*Figure 10. Vehicle operating costs as a function of speed according to a British model (Robertson & Ward 1998).*

### 3.5 IMPACTS ON INDIVIDUAL JOURNEYS

Most actual journeys consist of travel along a number of different road sections, often of widely differing characteristics, and liable to be affected in quite different ways by speed management. To estimate the effect of various speed management measures on such a journey would in principle require the appropriate cost model to be applied to each road section and the effects accumulated over the journey.

Again, to estimate the aggregate effect of speed management upon one particular road section would require the cost model for that section to be used to estimate the changes in costs to users of all vehicles travelling along that road section as part of their journey.



The availability of data to support such calculations is examined by *Robertson & Ward (1998)*. A number of Member States carry out systematic surveys of personal travel which provide reliable information about the distribution of lengths of journeys by car – showing for example that in Germany the longest 10 per cent of journeys account for nearly 60 per cent of vehicle-distance travelled, whilst the shortest 60 per cent of journeys account for only 10 per cent. There is also aggregate data from systematic traffic counts about the amounts of vehicle-distance travelled on roads in different broad administrative categories. But these sources of data provide no information about the use of different kinds of road in the course of the journeys. To estimate the total costs to vehicle-users of a speed management strategy, it is necessary to know how much vehicle-distance is travelled on roads in each of the categories into which these are divided for the purposes of speed management. And to estimate the distribution of the incidence of these costs among different kinds of vehicle users it is necessary to know, for different kinds and lengths of journey, what proportion of the journey is covered on each of these categories of road. To meet these two requirements will need new kinds of survey work, which need not be massive in scale, but will need to be skilfully designed and executed. The surveys will need to cover the use of all kinds of motor vehicles, not just cars (*Allsop 1998*).

These new kinds of information are particularly relevant to the valuation of travel time, if time changes per journey below a certain threshold are neglected in economic calculations as debated in Section 3.4.2. If this kind of approach is adopted in relation to speed management, it will be necessary to estimate the distribution of the incidence of travel-time changes in order to know for how many journeys the changes exceed the threshold and by how much.

### **3.6 EQUITY AND DISTRIBUTIONAL IMPACTS**

In principle optimal ranges of speed for any road could be determined by choosing speeds where the total benefits in relation to the total costs are highest. Such a method, however, does not take into account distributional impacts, the fact that gains from changes in speed for one group of people often mean losses to some other group. Another related concept is equity, which refers to the ethical desirability of distributing benefits or wealth among groups and individuals, and to the corresponding injustice caused by substantial uncompensated losses (*Lichfield et al. 1975*). From society's point of view equity and distributional impacts can be equally important as overall efficiency, sometimes even more important. As there are neither markets nor measurable prices for equity and distributional factors, they have traditionally been the domains of politicians. While efficiency in resource allocation is measured by figures like the benefit cost ratio, equity impacts are studied analysing the distribution of costs and benefits among regions, socio-economic groups, etc. (*Kallberg & Toivanen 1997, 1998*).





### 3.7 NETWORK LEVEL IMPACTS

If speed management permanently changes the accessibilities of locations in relation to each other, spatial socio-economic effects may occur in the long run. People and companies can move to other locations. For example, greater speed of travel allows a household to relocate farther from its workplace to areas where the household may be able to obtain a larger or otherwise more attractive dwelling for costs similar to those prior to the move. The decision to move farther from the workplace has a direct effect on the amount of kilometres travelled. Also, in the new location, some other mode of transport may be more attractive than the one used previously. Companies may naturally make similar kinds of decisions.

Studies on the impacts of changes in speed often consider only *link level* impacts, which usually means assuming that traffic volumes remain unaffected. *Network level* studies that take into account also the (indirect) impacts on traffic volumes are more laborious and rare. A particular problem with the assessment of network level impacts is the lack of knowledge of the elasticity between speed and traffic volume (*Kallberg & Toivanen 1997, 1998*).

### 3.8 PRIVATE AND SOCIAL COSTS

The divergence of private and social impacts is one of the major reasons why speed management is needed. The assessment of the socio-economic feasibility of a policy is based on the costs experienced by society. This is not equal to the sum of the costs incurred by individuals, because all costs are not perceived correctly by individuals. In the context of the costs (and benefits) associated with the speed of travel, even if we assume that each driver chooses his/her speed rationally,

*“there is no reason why the factors that lead drivers to choose particular speeds should result in levels of speed that are preferable from the point of view of society as a whole, because some important gains and losses to society resulting from vehicles being driven at different speeds are not experienced individually by their drivers (Allsop 1990)”.*

In principle, speed regulation by posted speed limits and speed limiters in vehicles could be largely replaced by pricing each kilometre of travel according to its full marginal social cost. This could be accomplished by setting a tax (or subvention) that would be equal to the difference between the social and private marginal costs. In practice such solutions do not seem likely for the foreseeable future. Furthermore, it is uncertain whether such solutions would be acceptable from the viewpoint of equity and distribution of welfare in society (*Kallberg & Toivanen 1997, 1998*).



## 4 PROCEDURE TO ASSIST DECISION-MAKERS CONCERNING SPEED MANAGEMENT

### 4.1 CONTEXT FOR DECISION-MAKING

The level of speed on a section of road is the product of individual choices of speed by the drivers using the road. For a driver and other occupants of the vehicle being driven, the most directly perceived consequence of choice of speed is travel time, which decreases as speed increases, though at a progressively diminishing rate. Operating costs increase with speed from the middle range of speeds upwards, but this effect is less directly perceived by drivers than the saving in time. Risk of accident increases as speed increases, but there is a widespread tendency of drivers to discount their own risk of involvement in an accident. Noise and exhaust emissions increase with speed, at least from the middle range of speeds upwards, but are borne largely by people other than the driver and fellow-occupants of the vehicle. The consequence of all these effects of speed choice, and of their incidence, is that the speeds chosen by drivers have a strong tendency to be higher than would be optimal for society under any reasonable relative valuation of the various above-mentioned effects of speed (*Allsop 1998*).

It follows that when the authorities responsible for regulation of road traffic engage in speed management, that is in policies and measures to influence drivers' choice of speed, they are usually seeking to reduce speeds. Speed regulation can also be seen as persuading vehicle users to forego some of the perceived advantages to them of higher speeds, in order to reduce some of the less well-perceived disadvantages to themselves and many disadvantages to others (*Allsop 1998*).

In doing so, the authorities have to gain the acquiescence, if not the enthusiastic consent, of the majority of drivers - that is the speed management policies and measures need to be acceptable in the balance they strike between the foregone advantage to vehicles users and the concomitant advantage to society.

In reaching decisions about speed management, therefore, it is helpful for the decision-makers to be as fully informed as is practicable about the effects that any speed management policies and measures they are considering may have, both in aggregate and in their distribution over the affected people. This is helpful not only to their own decision-making, but also in their task of consulting the affected people and assessing the acceptability to them of the envisaged policies and measures (*Allsop 1998*).

It is to help in this that the MASTER framework for assessing the effects of traffic speed has been developed and tested (*Kallberg & Toivanen 1997, 1998*).



## 4.2 FRAMEWORK FOR ASSESSING THE IMPACTS OF SPEED

### 4.2.1 Objectives

The main objective of the MASTER framework is to provide a tool for the overall assessment of the impacts of (changes in) speed (*Kallberg & Toivanen 1997, 1998*). Different impacts of speed were generally described in Chapter 3. The framework combines the effects of a given (change of) speed into a systematic presentation. Furthermore, the MASTER framework aims to be

- comprehensive in the sense that all relevant effects of speed are considered;
- easy to apply, recognising that this may require some tradeoff with precision;
- applicable from the level of single road sections to that of whole road networks, i.e. from the link to the network level;
- interpretable in monetary terms as far as the user wishes and within the limits of what is practicable, but without excluding impacts that are hard to express in monetary terms;
- transparent in that the bases of all the calculations are made explicit;
- easy to adapt to new information about the impacts of speed or to different valuations of its effects;
- flexible enough to allow users to apply their own weighting to different effects of speed; and
- able to present information about the distribution of impacts of speed, as well as about aggregate impacts.

### 4.2.2 Structure

Figure 11 summarises the direct and indirect impacts of the speed of traffic that the framework is capable of handling. The causal links from (a) to (j) are relevant in all cases, whereas those from (k) to (m) are considered only at the level of transport networks.

The MASTER framework consists of three distinct phases: 1) outlining, 2) measurement and 3) assessment. Each phase can be divided into a number of steps (Figure 12).

For practical implementation of the framework Excel spreadsheets are available to help in the calculations. They can be downloaded from the MASTER web site at <http://www.vtt.fi/yki/yki6/>.

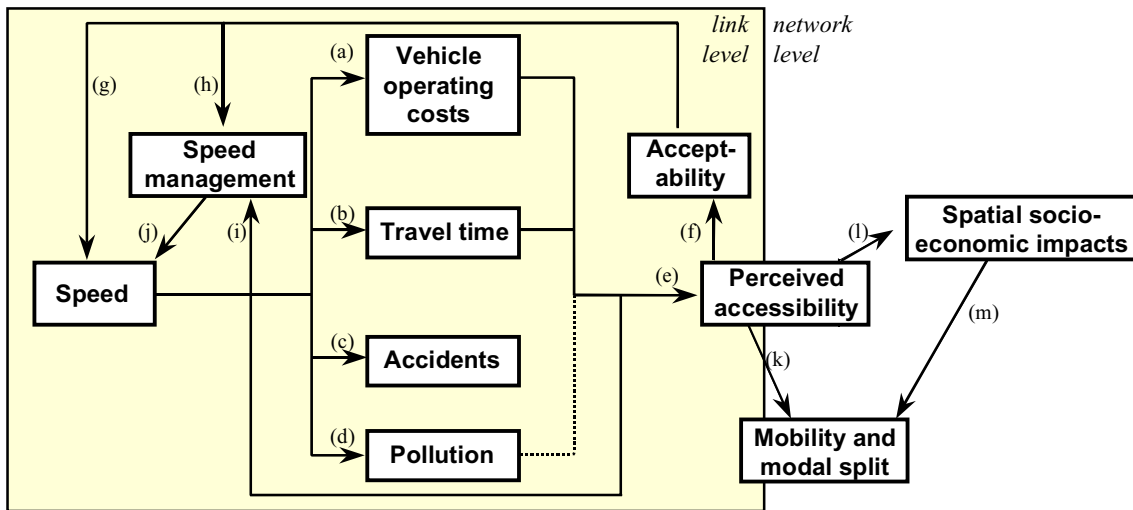


Figure 11. A summary of the direct and indirect impacts of the speed of traffic (Kallberg & Toivanen 1998).

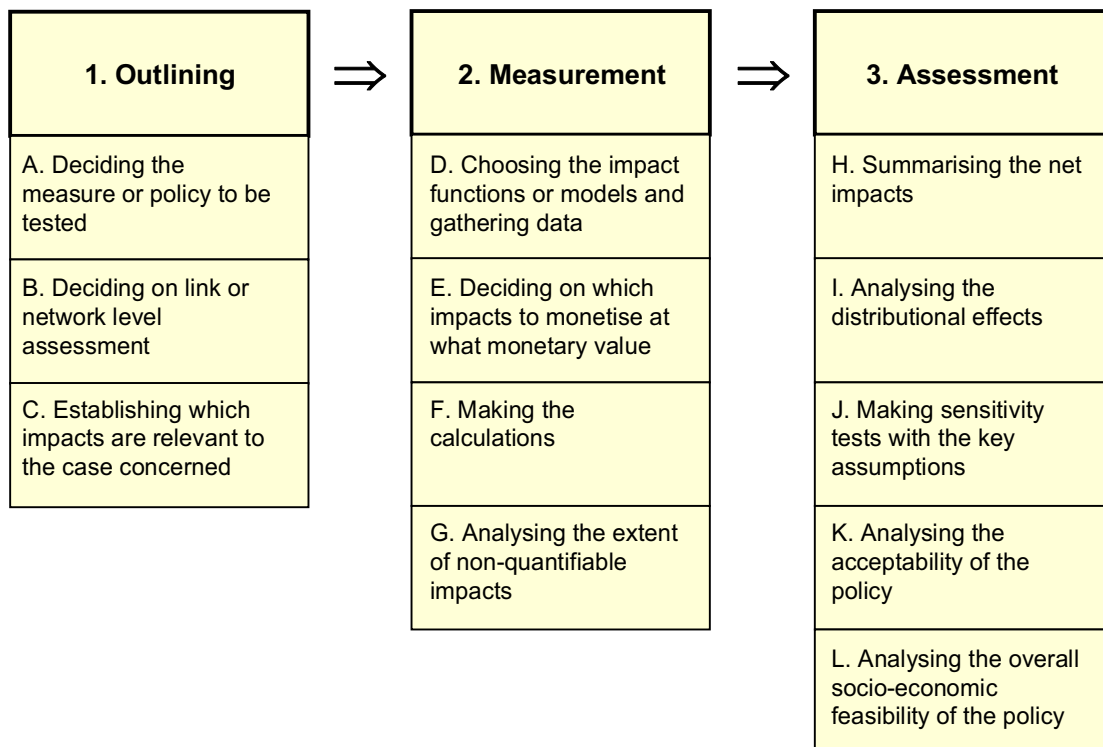


Figure 12. Structure of the MASTER framework (Kallberg & Toivanen 1998).



### 4.2.3 Scope

The framework can in principle be used to assess any measure or policy ranging from moderating the speeds of the fastest few per cent of vehicles on one particular section of road to a policy for reducing the speeds on all kinds of road throughout a region or country.

The MASTER framework allows the user to begin by specifying the measure or policy to be tested. The user then decides on a link or network level of assessment, and chooses the impacts that are included in the assessment. Possible impacts are:

- at the link level
  - accidents
  - exhaust emissions,
  - noise,
  - travel time,
  - vehicle operating costs, and
- additionally at the network level
  - rerouting,
  - change of mode of travel,
  - change of destination, and
  - land use transport interactions

For the included impacts, the user then

- chooses the impact functions or models for the quantification of impacts, gathers the relevant data for the existing situation and makes corresponding estimates for the new situation with the measure or policy being considered in operation;
- decides which impacts to express in terms of money and at which monetary valuations;
- makes the calculations; and
- analyses and describes the non-quantifiable effects.

The user is then ready to

- summarise the net impacts of the policy or measures;
- set out the distributional effects;
- make sensitivity tests with respect to key assumptions and input values;
- use the results to assist the process of consulting the affected people about its acceptability (in case the results are sufficiently favourable to the policy or measure for it to be worth investigating its acceptability); and
- use the results together with the outcome of consultation with the affected people to assist in the decision whether to go ahead with the policy or measure.



#### 4.2.4 Limitations

The limitations on the use of the framework lie largely in the ability of the user to specify impact functions and models, and assemble the range of data needed to implement these functions and models. These limitations become more severe as the required level of detail and precision of the calculations increase. The required level of accuracy that the user, the decision-makers concerned and the affected people being consulted will find adequate in turn depends on the context and of the policy or measure being considered.

Chapter 3 of this report have demonstrated that a range of relevant models and data exist that enable the speed-dependence of a range of relevant impacts of traffic to be quantified at the link level. Nevertheless, all of this information is not available in forms that are readily accessible to potential users of the MASTER framework (*Allsop 1998*).

At the network level, the user of the framework will need to implement appropriate assignment, mode choice, destination choice or even land-use transport interaction models to estimate revised flows of traffic on all affected links before applying link-based models of the various impacts.

### 4.3 APPLICATION OF THE FRAMEWORK

In accordance with the principle of subsidiarity, speed management, except possibly on the Trans-European Road Network (TERN) will for the foreseeable future be a matter for the Member States. Moreover, in many Member States the responsibility for regulation of much of the road system is delegated to regional or local authorities. Therefore many decisions about speed management will be taken by these authorities. For the framework to be useful to them, it will need to be made available as a piece of user-friendly software together with clear guidelines on its use, including the choice of functions and models for the various impacts and the gathering of suitable data. Some authorities will wish to apply the framework themselves; others will wish to commission consultants to apply it for them (*Allsop 1998*).

National governments or their agencies may well wish to apply the framework to nationally funded road networks or to examine the feasibility of national policies for speed management on other roads.

At the level of the EU the framework might be used to examine policies for speed management on the TERN. The main role of the EU in respect of the framework, however, may well be in promoting speed management across the EU by making it available in a widely usable form with associated functions and models for the various impacts, and corresponding specifications of the required data. Testing of the framework in three different countries, as reported by *Kallberg & Toivanen (1998)*, indicates that this should be feasible - though it will require substantial investment. In this way, the EU would add value to the separate efforts of individual Member States in the field of speed management.



The framework is adapted for application to every type of road from the residential access road to the multi-lane motorway. The differences between applications to different kinds of road lie in the choice between link and network levels, deciding which impacts are relevant, and choosing appropriate functions and models for these impacts according to the type of road.

The use of the framework is illustrated by a real-life example in Appendix 3.

#### **4.4 USE OF THE OUTPUTS IN DECISION-MAKING**

Two uses of the outputs from the MASTER framework in decision-making have been identified. One is to assist the process of consultation with people who will be affected by a proposed speed management measure or policy, with a view to assessing the acceptability of the proposed measure or policy. In consulting such people, it should be helpful to be able to make available to them the results of a transparent procedure for assessing the likely impacts and their distribution (*Allsop 1998*).

The second use of the outputs from the framework is in the subsequent decision-taking itself. This should be assisted by being informed by the outputs from the framework, which will then be considered alongside the results of public consultation and any other relevant material or considerations which the decision-makers choose to take into account in exercising their judgement and political responsibilities.

In no way is the framework intended to substitute for the judgement of the decision-makers. It is a tool to help them to exercise that judgement more effectively by being better informed about some of the principal likely consequences of a decision to go ahead with any proposed measure or policy for speed management.

#### **4.5 ACCEPTABILITY AS CRITERION FOR SPEED MANAGEMENT**

According to a recent survey 42 per cent of drivers in the European Union would prefer higher speed limits on motorways, 24 per cent on main roads and 10 per cent in built-up areas. At the same time, slightly more than half of the drivers expressed their support to 'a device in your car to assist you in not exceeding the limit' and the limitation of the maximum speed of vehicles by the manufacturers (*SARTRE 1998*). An important question is what kind of role should surveys like this have in speed management.

In a democratic society public opinion has an important role in decision-making. Consequently, public surveys about the acceptability of planned speed management policies are often desirable from the viewpoint of decision-makers. However, in the MASTER framework designed to assist decision-makers (section 4.2) acceptability has only a relatively minor role. This is because there are at least three good reasons why public acceptability is not necessarily a good criterion for decisions concerning speed management.



First, there is no reason to believe that drivers consider all impacts of speed when deciding on their choice of speed. Therefore, they may disregard impacts (e.g. environmental impacts) that are important from the point of view of society as a whole.

Second, drivers' choice of speed is often based more on their subjective assessment and beliefs of the associated costs and benefits, rather than research-based knowledge. Subjective assessments may be erroneous with regard either to the magnitude of the impact or its valuation.

These two points are the main causes of the divergence between private and social costs (see Section 3.8). Consequently, speeds that are considered optimal by majority of drivers are not necessarily optimal from society's point of view.

Third, double-counting is a potential problem in since acceptability is not independent of the distribution of impacts e.g. between motorists and pedestrians. It is likely that those who feel they gain from a speed change are in favour of it and those who think they lose are against. Therefore, if benefits and costs are properly handled, their net change should also indicate the 'net acceptability' of the policy, and analysing acceptability separately would lead to double-counting of the benefits and costs (*Kallberg & Toivanen 1998*).

Another point is that the impression about the acceptability of a certain speed management policy or measure given by the media can be biased and reflect mainly the opinions of some active interest groups. Furthermore, the results of interviews and questionnaire surveys typically depend on the selection of respondents, formulation of questions and whether the respondents have correct knowledge about the expected effects of the policy or measure.

Despite these problems, information on public opinion may help to formulate policies that are both socially beneficial and acceptable. The simplest way of acquiring this information is by asking road users and residents directly about their views of the planned policy. Stated preference techniques could be applied, for example. The structure of the interview or questionnaire, however, should be carefully designed and the respondents should be properly informed of all impacts of the policy in order to get an unbiased response.

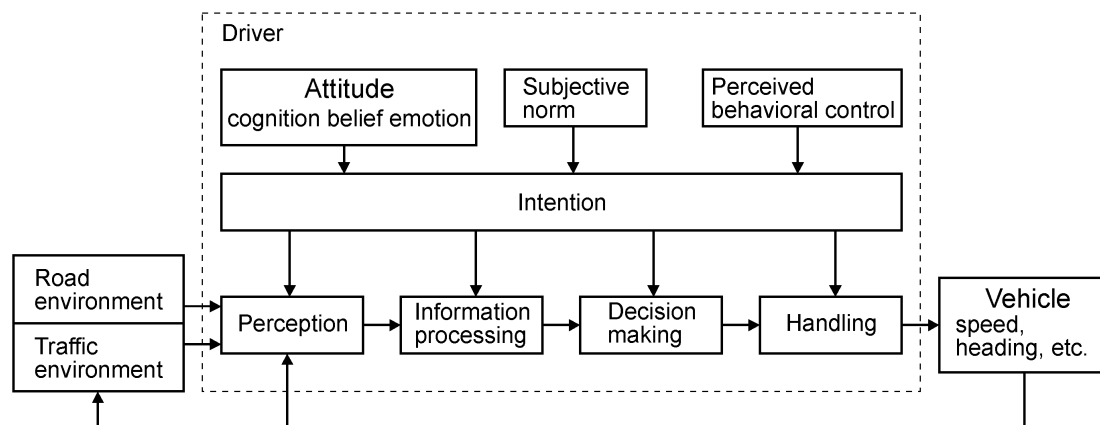




## 5 DRIVERS' CHOICE OF SPEED

### 5.1 OVERVIEW OF FACTORS AFFECTING SPEED CHOICE

The theory of planned behaviour by *Ajzen (1985)* is frequently used in traffic psychology. Models built on this theory indicate that driving *behaviour* is largely determined by *intentions*, which in turn are determined by *attitudes*, *subjective norms*, and *perceived behavioural control*. However, speed behaviour is not only driven by motivation, but also by external feedback factors as perceived by the driver, such as road design elements and the behaviour of other road users in his surroundings. In Figure 13 a combined overall model is given of the factors that influence drivers' speed behaviour. For example, enforcement measures will be much more effective when the road design is already in line with drivers' expectations concerning the behaviour that is to be expected from them.



**Figure 13.** Combined overall behavioural model to indicate factors that influence drivers' speed behaviour (van der Horst 1998).

In the project MASTER factors affecting drivers' choice of speed have been investigated mainly from two points of view. First, interviews of drivers and pedestrians were carried out in six European countries about the acceptability of present speeds and speed limits. In preparation for these interviews, an extensive literature review was carried out on the relationship between motivation and speed. Second, relevant aspects of road design elements with respect to driving speed behaviour were identified and quantified by experimental studies. Various speed-reducing measures are also identified and quantified.



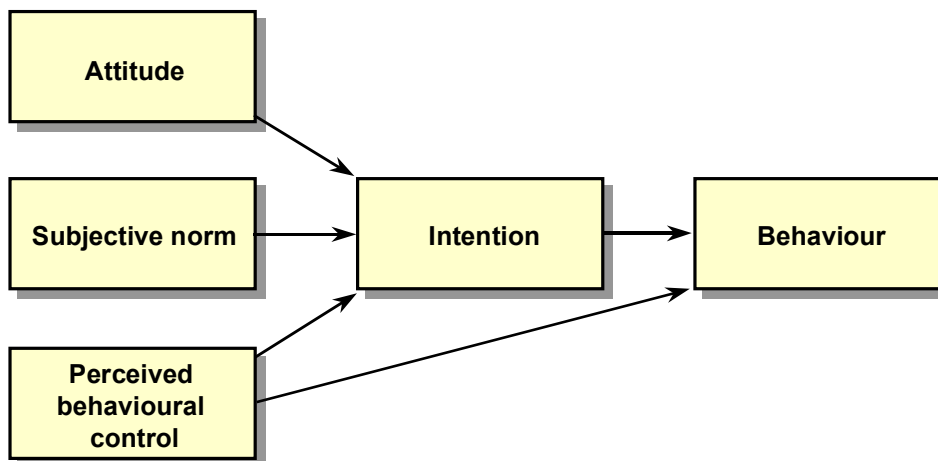
## 5.2 SPEED AND MOTIVATION

A literature study was conducted focusing on the preparation of surveys among road users (both motorists as well as pedestrians and cyclists users) about driving speeds and speed limits in areas within and beyond their own residential neighbourhoods (*Levelt 1998*). The information thus collected has consequences for the form and content of the questions to be presented in the survey as well as for the content of possible information campaigns. The results of this study are summarised in the following, and they were used in the preparation of the survey described in Section 5.3.

### 5.2.1 Theory of planned behaviour

The theoretical model normally used in traffic psychology is the Theory of Planned Behaviour (*Ajzen 1985*), an extension of the Theory of Reasoned Action (*Fishbein & Ajzen 1975*).

The theory of planned behaviour is illustrated by Figure 14. In short, the theory states that behaviour is motivated by intentions and by perceived behavioural control (do I have the means to behave?). The intentions are caused by attitudes and subjective norm (or the social perception). The attitude determines how favourable the behaviour is deemed to be, based on the valued beliefs (valued expectations) associated with the behaviour (the behaviour probably has certain outcomes, and I evaluate these outcomes as more or less positive or negative). The subjective norm is built on the perceived opinions of people judged as important with respect to this behaviour. The perceived behavioural control also influences the intention. When someone is convinced that he cannot perform the behaviour, he will probably not form an intention to do so.



*Figure 14. The elements of the Theory of Planned Behaviour (Levelt 1998).*

This theory is criticised by *Levelt (1998)* for insufficient account of affective domain, while there are indications that this domain actually contributes to the motivation for speeding behaviour.



## 5.2.2 Planning of questionnaires and information campaigns

As far as the form of the questions in the survey is concerned, determining an attitude is based on asking two kinds of questions: a question about the probability that a certain behaviour will lead to a certain consequence, and a question about how the respondent evaluates that consequence. The answers are then multiplied by one another during statistical analysis. Additional processing of these products (correlations, factor analysis) places high demands on the character of the original scales; this processing is possible only by using ratio scales. Since many attitude studies about speed and other traffic behaviour fail to take this rule into account, basing results on them becomes very difficult if not impossible.

As to the content of the questionnaires and information campaigns, both established and newly developed concepts can be found in the literature pertaining to road safety psychology and social psychology. Traditional methods of measuring attitude sometimes ignore the possibility that new motivations are going to be a factor and underestimate the factor of feelings people may have in the future. Attention is requested for such attitude characteristics as strength, accessibility, ambivalence, importance and consistency as well as for the difference between cognitive and affective aspects.

Attitude is understood to mean an internal situation that causes a person to respond favourably or otherwise to an object (*Wittink & Levelt 1994*). The object has a characteristic and this characteristic is evaluated in either a positive or a negative sense. Often, attitudes are only considered applicable to behaviour, implying either a positive or negative evaluation of the consequences of behaviour. This attitude predisposes someone to actually perform or not perform the behaviour. The attitude therefore has two components: the conviction that the behaviour has a certain consequence, and an evaluation of that consequence. An attitude does not lead directly to behaviour. People often insert an intention that is elicited by an attitude. The intention then leads to the behaviour.

Attitudes can be seen as anticipated emotions: people weigh the advantages against the disadvantages as well as the pleasant and unpleasant feelings to be expected. These do not necessarily have to agree with the emotions that will arise when the time comes. Gradually, more and more is becoming known about the effect that emotions have on the choice of a certain speed and on the assessment of another person's speed, as well as about the use of emotional appeals in campaigns. Such emotions as guilt, regret, fear, anger, boredom and pleasure occupy an important place here. Emotion theory offers a good framework for studying these emotions as the basis for motivations. Attention should be given to investigating moods since moods appear to be important for all kinds of operations and behaviours.



### 5.2.3 Attitudes towards speeds and speed-reducing measures

Drivers' choice of speed is affected by the driving speed of fellow road users and by how people evaluate the opinions and reactions of significant others (family, friends, passengers, the police and the government). The relative importance of attitudes and social norms depends on the kind of road in question. People are not only subject to but also exert social influences. Information campaigns can make use of this fact. People's intentions and behaviours are also affected by the control people think they have over their behaviour. People not only have the feeling that it is difficult to control driving speed behaviour, but they also overestimate their own ability to control the consequences of speed.

People vary in their propensities for experiencing emotions such as fearfulness as well as the way in which they manage their emotions. A familiar factor in speed behaviour is that of sensation-seeking. The need to be in control in difficult situations is probably a primary factor in driving at higher speeds; the need for danger plays a lesser role. A second possibility is aggression. Aggression probably leads to all kinds of dangerous behaviour, including driving at high speeds.

*Levelt (1998)* presents results from a large number of studies concerning speed behaviour and attitudes towards speed and speed-reducing measures. Some of the findings are summarised in the following.

- A reasonable relationship is usually found between directly and indirectly measured attitudes (the sum of consequences times evaluations), between attitudes and speed intention and between speed intention and reported behaviour (*Rothengatter 1994*).
- The principal attitude elements that determine speed intention and behaviour, where it concerns driving over the speed limit, are in descending order: pleasure in driving, risk, travel time and costs. Pleasure of driving is especially important on motorways, but insignificant on urban trunk roads (*Vogel & Rothengatter 1984*).
- Attitudes towards speeding are less negative than towards drunk driving tailgating or dangerous overtaking. The beliefs behind the attitude towards speeding included: rapid arrival at destination, driving fast is pleasant, adapting to the speed of others, small probability of getting caught and fined, no hazard to pedestrians, and small probability of an accident (*Parker 1991*).
- Motives for speeding are mainly to adapt to the speed of others, because one is in a hurry, because one is not aware of the limit, and because one enjoys it. Motives for keeping to the limit are safety, legal obligation, risk of being fined and not being in a hurry (*Pol et al. 1994*).
- People who drive very slowly do it because: they wish to drive slowly, poor condition of the car, subjectively experienced safety, lack of confidence or using a car-phone (*Rajalin & Summala 1996*),
- People are motivated to drive at increasingly faster speeds (*Summala 1988*).



- People are satisfied with the prevailing speed limits, but they are also willing to accept lower limits if it concerns European regulation (*SARTRE 1994a, 1994b*).
- Residents generally like the introduction of low speed limits (30 km/h) in their own urban neighbourhood in connection of traffic calming schemes. Children in particular, and pedestrians in general, were identified as the main beneficiaries (*MacKie & Webster 1995*).
- The acceptance of lowered speed limits (30 km/h) increases significantly following the introduction of the measure among all road user groups (*Sammer 1994*).
- According to speed-reducing measures are judged more favourably the more effective they were considered to be, and the less they caused personal disadvantage (reduction of choice, increased journey times or discomfort) (*Carthy et al. 1993*).
- People generally have a positive view of police enforcement for speeding (*Carthy et al. 1993, Oei & Goldenbeld 1994, 1995a, 1995b, 1996*).
- In a New Zealand survey it was found that according to 80% of respondents the new *demerit points* regime against speeding was either acceptable or not severe enough (*Perkins 1990*).
- People who rarely or never speed themselves underestimated the number of people who regularly speed; whereas people who often speed, overestimated it (*Manstead et al. 1991*).
- Local inhabitants often demand lower speeds in their own neighbourhood (*Cairney et al. 1994*), and are generally pleased with achieved speed reductions (*Herrstedt 1988*). They also argue in favour of stricter police enforcement (*Carthy et al. 1993*).
- People may also have a sense of territory in their local area and ignore local regulations, if they feel they are there mainly to control through traffic (*Jones 1989*).
- Changing speed behaviour by means of influencing attitudes is almost impossible. Neither the consequence, i.e. driving pleasure, nor its evaluation can be influenced (*Rothengatter 1988, 1994*). Several studies are in line with this conclusion (e.g. *Spolander 1989, Nolen & Johansson. 1993, Rooijers 1991, Parker 1994*), although also different results exist (e.g. *Menting & Steyvers 1996, Senior et al. 1993*).



### 5.3 ACCEPTABILITY OF PRESENT SPEEDS

#### 5.3.1 Research method

Altogether 1200 road users in six European countries (200 in each country) were interviewed about acceptability of levels of speed and of measures to limit speed (*Risser & Lehner 1998*). In each country, 50 road users were selected in each of four situations:

- between junctions on a 2- or 3-lane urban road;
- in a narrow one-way urban street with parked cars;
- at an uncontrolled junction with car drivers interacting with pedestrians and cyclists while going ahead or turning; and
- at the entrance to a village.

About half of those at each site were interviewed as being car drivers and the other half as being pedestrians (including a few cyclists). The responses were sufficiently consistent across the 6 countries for the data for all 1200 road users to be interpreted largely as a whole.

The model underlying the interviews is presented in Figure 15.

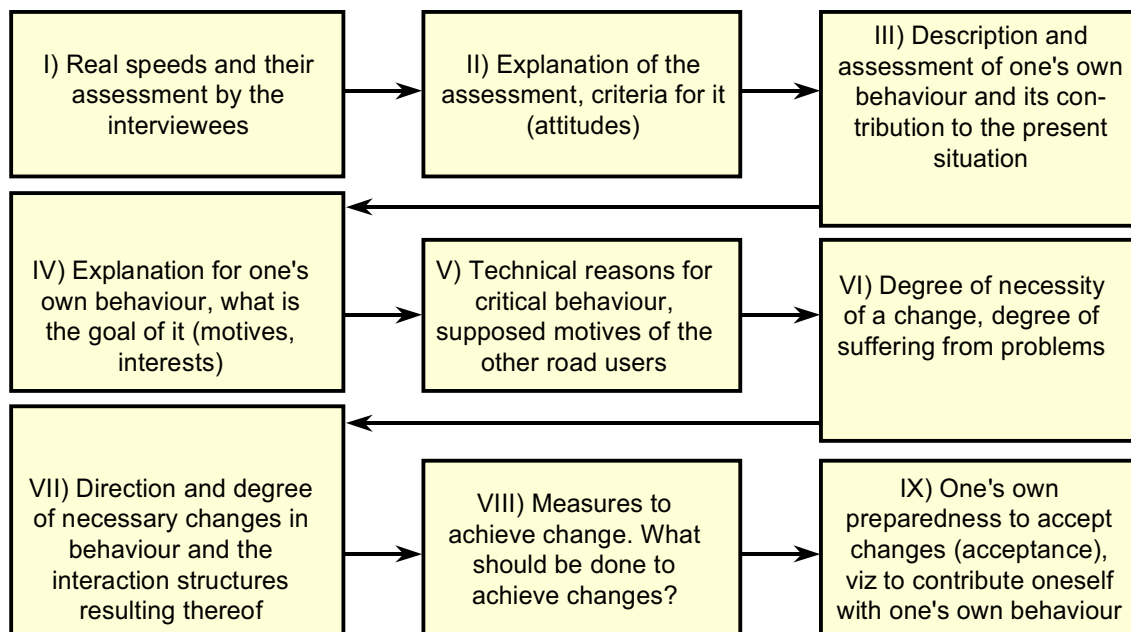


Figure 15. Structure of the interviews (*Risser & Lehner 1998*).



### 5.3.2 Results from interviews

The majority of both car drivers and pedestrians consider the current speed limits in as appropriate. However, about half of those interviewed as car drivers and about three-fifths of those interviewed as pedestrians thought that current speeds in general were too high. Asked about speeds of traffic at the sampling sites, over one-third of those interviewed as drivers and over half of those interviewed as pedestrians thought they were too high, whereas less than 10 per cent thought they were too low.

When asked about situations in which speeds should be reduced, both groups mentioned the presence of pedestrians, especially children and the elderly; those interviewed as car drivers were more likely to mention bad road, traffic or weather conditions. The same conditions, together with the presence of pedestrians, were mentioned when interviewees were asked under what circumstances drivers should drive below the speed limit. The likelihood of enforcement was also mentioned as a reason for doing so.

Asked whether measures should be taken to change the speed at the interview site, over a third of those interviewed as drivers and nearly half of those interviewed as pedestrians said yes, and a clear majority of both groups favoured reduction.

There was an appreciable tendency for those interviewed as drivers to say that they drive somewhat slower than others and that they exceed speed limits less frequently than others, and for less selfish reasons. More than half of the car drivers and even more pedestrians think that speed limits should be respected under all circumstances. Both groups have the impression that speed limits are exceeded rather often, especially on motorways and on rural roads.

High speed was also mentioned by both groups of interviewees as one of the aspects of their use of the roads that they felt was dangerous. More than three-fifths of each group said that they often encountered dangerous situations. Similar proportions regarded driving at high speed as aggressive and as reckless, and over 85 per cent regarded it as dangerous.

Both drivers and pedestrians realise that inappropriate speeds have negative consequences for residents' life quality. Pedestrians experience vehicle speeds as too fast more often than car drivers. Consequently, pedestrians are more in favour of speed-reducing measures than car drivers, especially at sites where they have to interact with car drivers.

Pedestrians consider measures that affect car drivers' behaviour directly, such as enforcement by police, non-stationary speed checks, speed humps, and speed limiters in cars, as more effective than car drivers do. Car drivers consider measures that do not directly affect their behaviour, such as clear and well indicated speed limit signs, better road markings, and better information about the relationship between speed and accident risk, most frequently as effective. Car drivers also think that the effectiveness and acceptance of measures is higher when they do not affect their behaviour directly.



Large majorities of both groups of interviewees agreed with a range of statements of advantages of lower speeds, including statements about the quality of urban life as well as statements about road safety.

All in all these findings indicate clear dissatisfaction with current levels of speed, among drivers themselves as well as among vulnerable road users, and in terms of the quality of urban life as well as road safety. There is a readiness at least in principle to see speeds reduced. This indicates that, notwithstanding current choices of speed by drivers, the climate for speed management policies for moderating speed may well be favourable.

### **5.3.3 The use of results in marketing and decision-making**

*Risser & Lehmer (1998)* demonstrate that ‘selling’ traffic safety measures including speed managing measures is a communication process according to a general marketing model. The steps in the model include, for example, a) definition of what is going to be marketed, b) learning about the customer, c) provision of understandable and clear laws and regulations, d) distribution of the product to relevant groups in the right context, e) communication of information about the product in a way that is appreciated by the customers, and f) provision of incentives for the intended behaviour. The results derived from the interviews clearly showed that traffic safety implications are aspects that all road users consider to be important, when they are asked about the importance of speed limits and of road users’ compliance. But car drivers connect dangerous situations with the presence of other car drivers and not so much with their own behaviour. However, mostly in connection with being in a hurry or not wanting to disturb the traffic flow, car drivers agree that they contribute to speed problems. Arguments should be related to this aspect and combined with the perspective that car drivers are well aware that inappropriate speeds cause serious problems for pedestrians and residents. The persons to be addressed, should also be reminded with facts that speeding occurs frequently and everywhere, i.e. speeding is not a marginal problem. The results also showed that for communicating with the public one should focus on the advantages of lower speeds and what they can contribute to the quality of life for residents. Since car drivers in their role as residents would benefit from a better speed management as well, the usefulness of traffic safety measures for residents should be made more transparent. Another way of increasing the acceptance of traffic safety measures is to communicate that even when better-adapted speeds are felt restrictive by drivers from their point of view, they help to improve the situation of others.

## **5.4 ENFORCEMENT**

The results of a literature review by *Oei (1998)* on the effects of enforcement on speed behaviour and safety are summarised in the following.

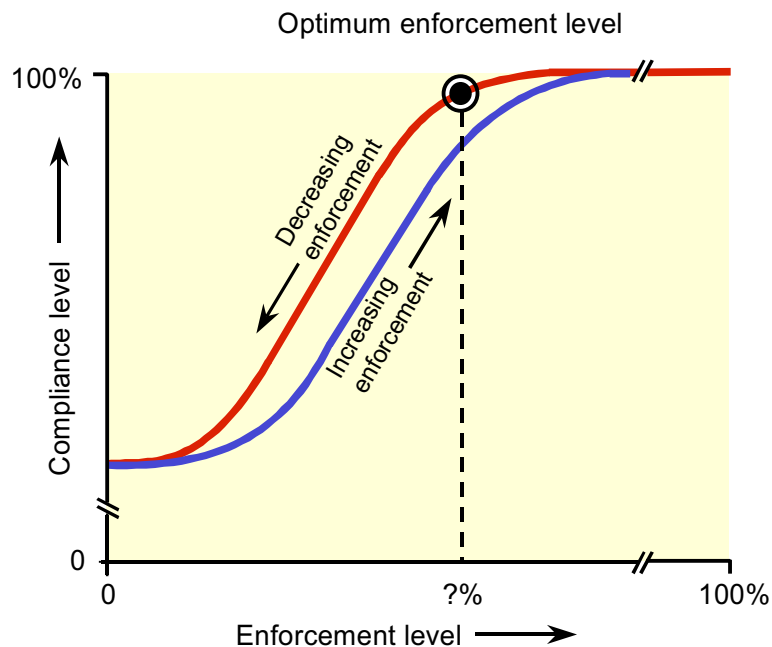




### 5.4.1 Effects of speed enforcement

The purpose of speed enforcement by the police is to keep actual driving speeds within the legal limits. Enforcement measures can be effective only when the probability of getting caught, as perceived by the driver, is relatively high. Speed enforcement at specific problem locations or on specific routes can significantly decrease speeds. The impact of enforcement on actual speeds depends on several factors, e.g. a) actual speed level compared to speed limit, b) intensity of enforcement (risk of getting caught), c) penalty system, and d) publicity.

It is suggested suggests that a 'hysteresis' type of curve in general reflects well the relationship between the level of enforcement and the level of compliance (Figure 16).



**Figure 16. Hypothetical relationship between enforcement level and compliance with a speed limit (Oei 1998).**

The effects of traditional speed enforcement where police officers measure speeds by radar and stop speeders for ticketing are typically limited in time and space. Furthermore, such enforcement is rather resource-intensive and not necessarily very cost-effective.

Speed cameras have proved to be effective and economic in many cases but can also be resource consuming if the law requires that the speeding driver must be identified from the photo. Modern technology offers several relatively cheap and effective means for speed enforcement provided that the driver does not have to be identified, but instead the owner of the vehicle can be held responsible. An example of such solution is an electronic identification device in the vehicle that could be used also for other purposes, such as for collection of road tolls and parking fees. At the moment such systems probably lack public support (Oei 1998, van der Horst 1998).



Speed enforcement at specific problem locations or on specific routes has a reducing effect on speed, as several examples show:

- An automatic speed warning system near a school could result in a speed reduction of 5 km/h. Speed enforcement at four urban intersections (in combination with red light enforcement) resulted in a reduction of the percentage of cars with a speed > 10 km/h above the speed limit of 50 km/h between 12 and 1%.
- Experimental studies with automatic speed warning and enforcement measures on specific routes resulted in speed reductions of about 2 to up to 8 km/h, with most of the time also an obvious reduction in accident rates.
- Area-wide enforcement measures on rural roads in the Netherlands resulted in speed reductions of about 1-2 km/h, though without clear reductions in accident rates.
- In an urban area speed reductions of 2-4 km/h were found together with a reduction in accident rates of 14%.
- A very intensive enforcement campaign in Victoria, Australia, with 2500 camera sites, 54 radar camera systems resulting in the checking of the speed of every car nine times a month, resulted in no decrease in the average speed level, but in a clear reduction of excessive speeds. Over a period of five years a 21% reduction of collisions, 38% in major injuries, and 51% in fatalities was achieved. Unfortunately, the effects of enforcement on speeding and on drinking and driving could not be separated from each other in this study.
- In general, effects of a single enforcement control last from three days and of repeated enforcement checks up to 6 to 14 days. Effects of a stationary parked clearly visible police car resulted in a speed-reducing effect over a length of 2-2.5 km from the actual checkpoint. A police car randomly moving around along a stretch of road caused speed reductions as far as 20 kilometres away from the car.

#### **5.4.2 Recommendations for speed enforcement**

A number of recommendations for effective speed enforcement are given on the basis of the literature study for example:

- Explicitly and quantitatively formulated government policy objectives regarding speed and accident reduction are needed.
- Because of higher efficiency of speed-camera enforcement compared to traditional speed enforcement where speeders are stopped, the first type of enforcement is recommended.
- It is recommended that the car owner is made primarily responsible for offences committed with a car.
- A point demerit system might enhance the efficiency and effectiveness of the enforcement endeavour.
- For enforcement to be accepted by the public, it is of importance that the objective is primarily prevention and accident reduction, and not punishment or financial gain.



- Enforcement should always be preceded and combined with publicity to inform the public about the danger of speeding, the enforcement method, and the effects achieved. This will prevent overloading the processing of speeding tickets at the start of the campaign. Publicity should be aimed at target groups.
- Fore warning of speed enforcement is functional where the enforced location or route is selected, based on a safety and speed problem.
- On a road network enforcement is recommended to be randomized in space and time (unpredictable). No fore warning should be given except through publicity. A sign informing drivers that their speed has been checked can be given down stream of the speed check.
- Use of new electronic technologies will increase the efficiency and effectiveness of the enforcement process. Such as automatic registering, reading, and identification of speeding cars. A high subjective and objective frequency of speed checks can thus be reached.

## 5.5 ROAD DESIGN

Apart from all kind of internal factors that influence drivers' speed choice such as motivation, intentions, emotions and the like, also road design and the manner the road is perceived by the road user may considerably contribute to drivers' speed choice (Figure 13, page 35). As speed perception depends on cues in the visual environment, a proper design of the road environment may bring drivers' speed choice and expectancy more in line with what is considered to appropriate in the given circumstances (*Van der Horst 1998*).

Four studies were conducted on the relationship between road design and speed. First of all, a literature study (*Martens et al. 1997*) gave an overview of road design elements that affect driving speed. Secondly, a survey was conducted in European countries to find out speed-reducing effects of different counter-measures that were not reported in literature (*Martens & Kaptein 1998*). A third study looked at the relationship between subjective road categorisation and driving speed (*Kaptein & Claessens 1998*). A fourth study investigated how drivers learn to classify correctly categories on the basis of feedback only, without knowing which design elements provided this information (*Kaptein et al. 1998*). These studies are summarised in the following.

### 5.5.1 Literature review and survey

*Martens et al. (1997)* conducted an extensive literature review to identify relevant road design aspects that influence driving speed behaviour and the effects of several speed-reducing measures. *Martens & Kaptein (1998)* conducted a survey among road administrations in different European countries to find out whether their experience with physical speed reducing measures practice was in agreement with the findings of the literature review. A summary of their findings is given below.



An effective way to reduce driving speed is to adjust the road layout in order to match the image, as provided to the driver, with the speed limit. Then drivers have the idea that speeding is not appropriate, and they do not feel they are forced to decrease their speed but show the appropriate speed behaviour rather voluntarily.

**In urban areas** and especially in residential areas and traffic calming zones speed humps and road narrowings can be effective in reducing driving speeds. Also road surface treatments can reduce speeds. However, also negative side effects are reported such as decreased driving comfort at low speeds, abrupt braking patterns and increased noise levels. Converting traditional junctions into roundabouts can significantly reduce speeds.

**Rural single-carriageway roads** display the most diverse speed choice patterns and frequently score highest in accident rates. On these higher speed roads, at specific locations driving speeds can be reduced by transverse road markings or transversely placed rumble strips. If the distance between transverse markings or rumble strips decreases while approaching the dangerous location, this usually leads to a reduction in speed, since this creates an illusion of acceleration. Longitudinally placed rumble strips that reduce comfort when taken with high speeds, require more accurate lane keeping, which is decreases driving speed. Advisory speed signs may serve as a warning for a dangerous location, but will only lead to actual speed reductions if drivers understand the reason for the warning.

One way to reduce driving speed, both on urban and rural roads, is by means of decreasing visibility distances. In this way driver's uncertainty is increased and in order to achieve better anticipation, they have to slow down. Decreased visibility distance can be achieved by increasing the amount of curvature, rising and falling gradients, buildings and overgrowth. Increasing the amount of visual information in such a way that the angular speed at the border of the peripheral field of vision will exceed 2 radians per second may lead to speed reductions, since drivers will try to avoid such values due to the experienced visual discomfort. Disadvantages of these measures should be taken into account, since they can decrease driving safety when drivers do not reduce their speed as much as required. Therefore, it would be wise to combine measures like these with for instance road markings or transverse rumble strips to warn drivers to slow down.

**Motorways** are the roads with the highest design standards. Usually, the concept of design speed is used, a speed a driver can maintain comfortably under favourable traffic and weather conditions. The whole geometric design is based upon that assumption. Drivers will have a high level of expectancy about this and behave accordingly. In substandard situations on motorways, drivers should be warned explicitly. More and more, Variable Message Signs are used to regulate and guide the traffic on motorways with dynamic speed limit signs. For example dependant on the visibility conditions, a fog warning is given together with an appropriate speed limit. In the Netherlands, such a system resulted in a 8 to 10 km/h extra speed reduction due to the system in dense fog conditions (*Hogema et al. 1994*).



Most road design adaptations, as discussed above, lead to the best speed-reducing effects if they are combined with other adaptations in road design. This way, speed reductions can be larger since the measures work in the same direction.

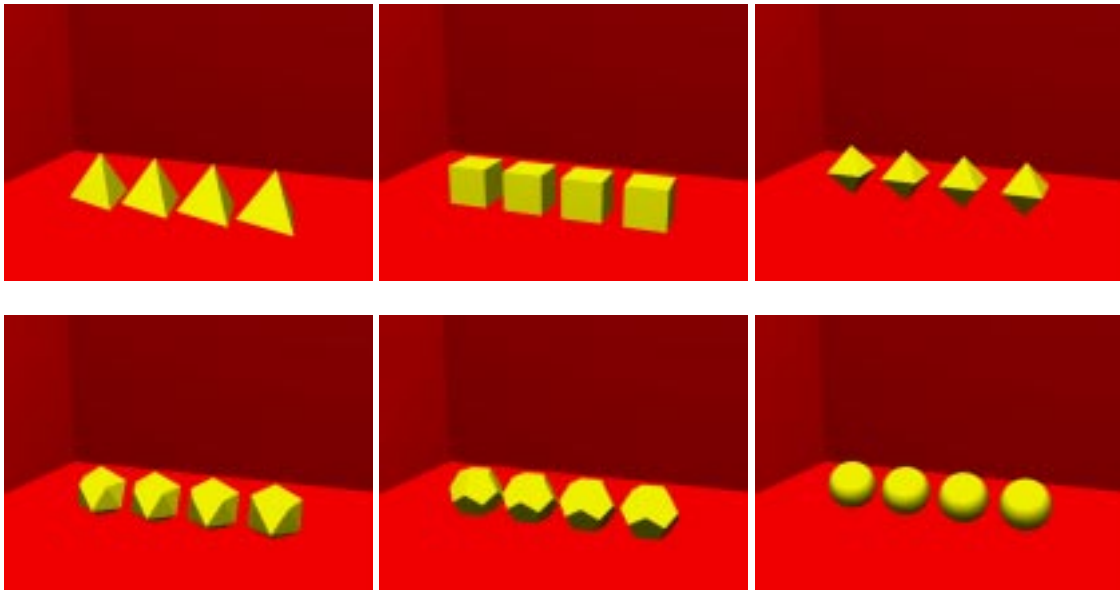
By providing drivers with the idea of an increased risk for high speeds, driving speeds can be reduced on all kinds of roads. Ideally, drivers' perceived (subjective) risk should reflect correctly the actual (objective) risks, or even overestimate them. Reducing road width asks for accurate steering behaviour and increases the perceived risk of running off the road or hitting other vehicles. Placing obstacles along the side of the road works much in the same way. The problem with these measures is that they also increase the actual risk of running of the lane and colliding with an oncoming vehicle or an obstacle for those drivers who do not reduce their speed as intended. Ideally, only the perceived risk of high speed driving should be increased. One way to achieve this could be the reduction of lane width without reducing pavement width.

Only limited and partly biased responses were received in the questionnaire survey among European road administrations about physical speed-reducing measures (*Martens & Kaptein 1998*). According to the results, different types of measures generally have an effect on driving speed. Combined measures, especially when the image of the entire road section is changed (e.g. 30 km/h zones) had the largest effects. The results of the survey and the literature review were generally completely in line. Currently the largest reductions in driving speed are realised with speed-reducing measures that physically restrict driving at high speeds such as speed humps and chicanes. Roundabouts have primarily a positive safety effect.

### 5.5.2 Categorisation of road environments

*Kaptein et al. (1998)* developed a method that can be used to find dimensions (characteristics) that contribute to better recognisable and distinguishable road categories. Little research has been devoted to the way this category learning takes place. *Saiki & Hummel (1996)* investigated one potential perceptual constraint on interactions between properties in object category learning. They used a method that is based on the notion that differences between categories are more distinctive to the extent that they are learnt more easily. *Theeuwes & Diks (1995)* conclude that environments are mentally represented in exactly the same way as objects and these representations develop by experience. In the present study an approach inspired by Saiki and Hummel's method, was applied in a series of five experiments. A sixth experiment was conducted to link these environment characteristics with subjects' estimates of their driving speed.

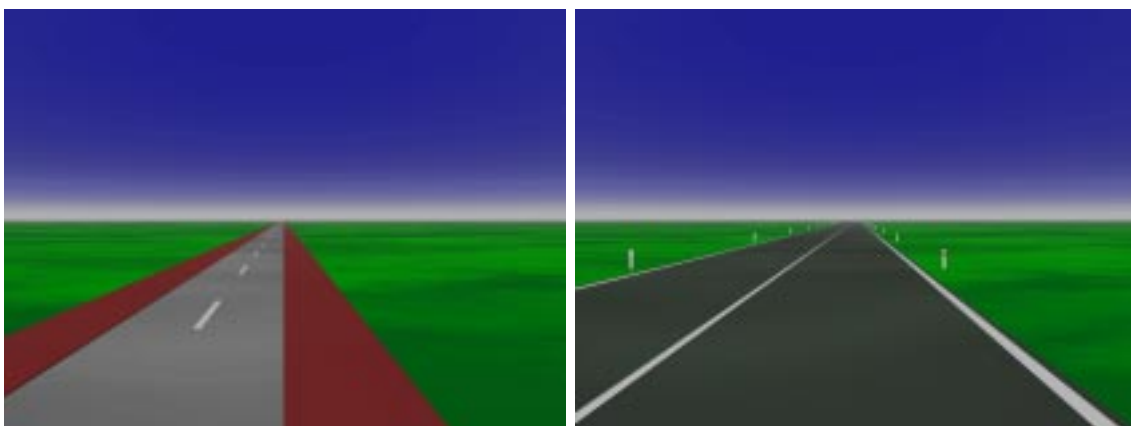
Experiment 1 was a pre-test to select equally salient levels from the different dimensions. To concentrate on basic principles of classification, in first instance artificial environments were used as stimuli (Figure 17). It was tested how difficult it was for subjects to learn to classify an environment on the basis of differences within a single dimension only. Subjects appeared to be able to correctly classify stimuli on the basis of each of five dimensions, of which some were relatively easy to learn and other relatively difficult.



*Figure 17. Examples of the six shapes used as stimuli images for Experiment 1 (Kaptein et al. 1998).*

In an subsequent experiment it was tested to what extent subjects were able to correctly classify environments when one out of three relevant dimensions provides deviant information. Results showed that subjects were able to learn categorizing on the basis of one or two dimensions, but could not correctly learn to use information from three stimulus dimensions together. They used two out of three available dimensions, and ignored the third one.

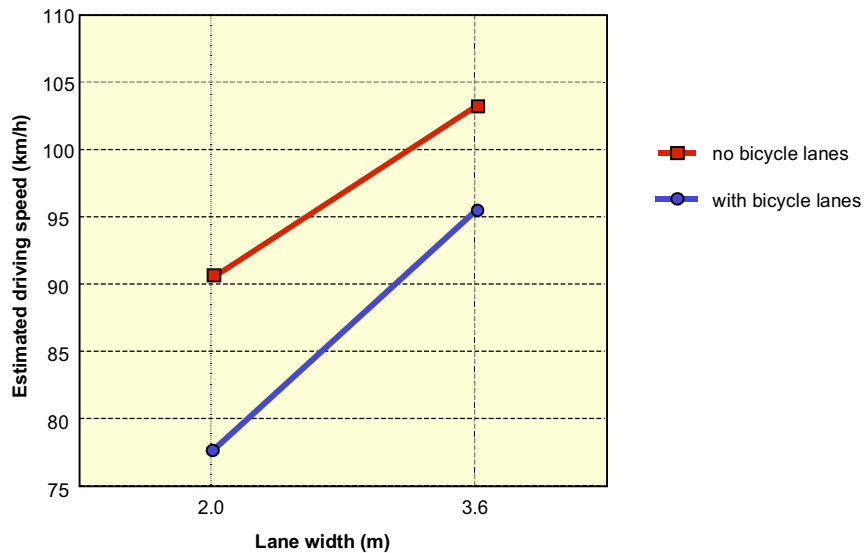
Experiments with road environments used as stimuli lane width, centre-line marking, road surface colour, bicycle lanes and reflector posts (Figure 18). The results strongly resembled the results of the abstract environment studies. Subjects only used two stimulus dimensions that were learnt most easily, and ignored a third one.



*Figure 18. Examples of stimuli representing road environments in the experiments (Kaptein et al. 1998).*



For the road environments presented subjects' estimated own driving speeds were, on average, about 92 km/h. Neither centre-line marking (interrupted/continuous), road surface (light/dark grey), or reflector posts (present/absent) influenced these estimated driving speeds. Both lane width (2 vs. 3.6 m) and red bicycle lanes (present/absent) considerably affected estimated driving speeds with the narrow lane width and presence of bicycle lanes having the lowest estimated speeds (Figure 19).



**Figure 19.** Estimated driving speeds for two levels of lane width and red bicycle lanes (absent/present) ((Kaptein et al. 1998).

### 5.5.3 Effects of cognitive road classification on driving speeds

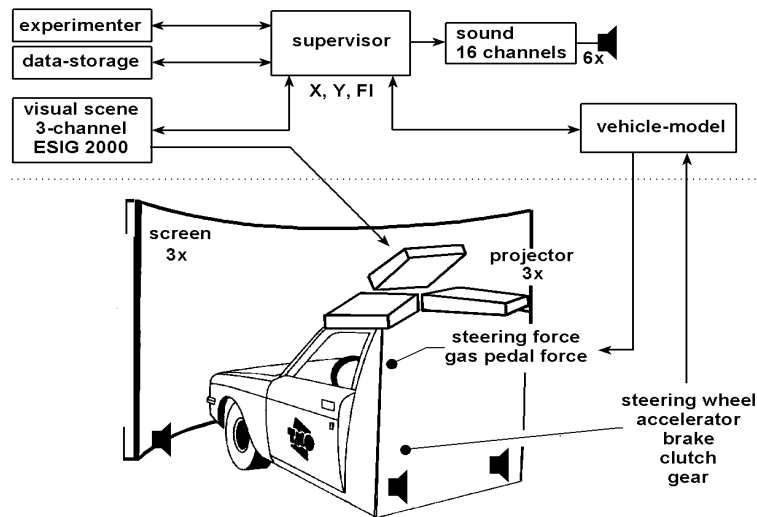
Since physical measures only force road users to reduce speed, but does not let them choose this voluntarily, a better solution is to design roads that are 'self-explaining'. By designing a road that provides a speed image that is in accordance with the actual speed limit, drivers are persuaded to choose appropriate driving speed more or less automatically. The Self-Explaining Roads (SER) concept advocates a traffic environment that elicits safe behaviour simply by its design. Therefore, it is important that the function and use of roads match the way people subjectively categorise these roads. At present, subjective road categories do not seem to correspond with the official road categories.

According to the SER concept, road users classify road scenes into categories. Each type of road has its prototypical representation, so individual roads do not have to be stored (and remembered) separately. Prototypical representations of road scenes develop through experience and constitute the basis for categorising road environments. As soon as an unknown road is encountered, existing schemes and their typical characteristics are used to categorise this road as a member of a subjective category. In order to obtain Self-Explaining Roads, it is important that the design of the infrastructure is adjusted to the way the road environment is categorised in the 'heads' of its users (*Theeuwes & Diks 1995*).



Successful categorisation may lead to a timely anticipation of possible events. Inadequate categorisation induces wrong expectations that may lead to human errors in perception and judgement on appropriate speed choice and consequently in an increased accident risk.

*Kaptein & Claessens (1998)* investigated in a driving simulator (Figure 20) experiment to what extent cognitive road classification determined driving speed.



**Figure 20. The TNO driving simulator (Kaptein & Claessens 1998).**

In the experiment 48 subjects drove in the simulator three sessions, the duration of each session was about 40 minutes. The road network they drove consisted of road sections in four different road categories (Table 4), and the design in each category varied between Current road (CR) and Self-explaining road (SER) design. The length of the road sections was 1300 m, and speed measurements between 800 and 1100 m were used in the analysis.

**Table 4. The four official Dutch road categories used in the experiment. For each category the speed limit and the possible occurrence of other traffic is given (Kaptein & Claessens 1998).**

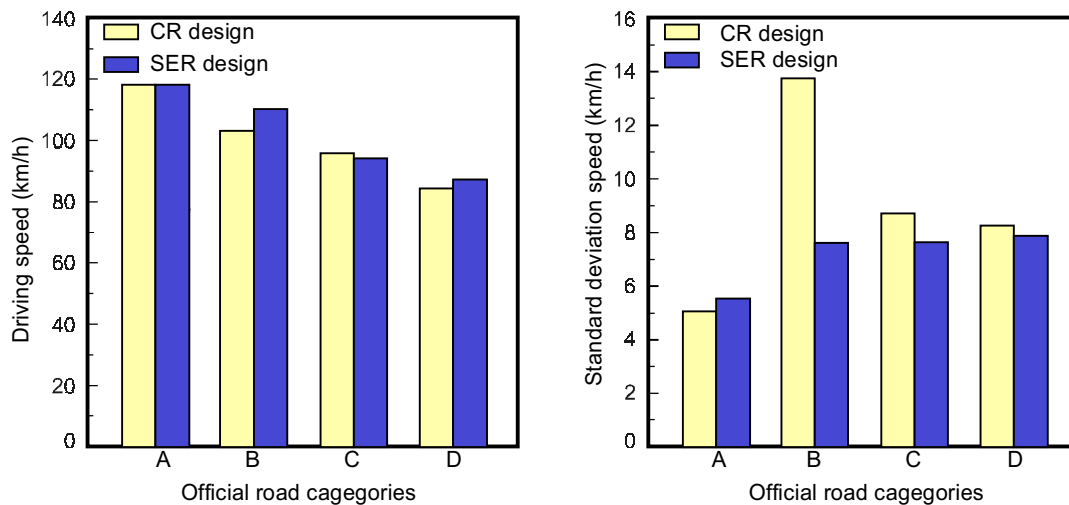
Category	Speed limit	Cyclists	Slow motor vehicles	Oncoming traffic	Crossing traffic
A Motorway	120	-	-	-	-
B Motor-road	100	-	-	+/-	+
C 80 km/h road for fast traffic	80	-	+	+	+
D 80 km/h road for fast + slow traffic	80	+	+	+	+





Compared with Current roads subjects were able to categorise Self-Explaining Roads with a selective and systematic application of road characteristics more in accordance with the official road category system.

According to the results average driving speed was higher on higher category roads, for both CR and SER design. On SER 100 km/h motorways subjects' driving behaviour was more in line with what was intended than on roads of the current design. On 120 km/h motorways and 80 km/h roads no such effect on mean speed was found, but a more consistent road design within categories led to more homogenous driving speeds ( Figure 21).



**Figure 21. The effects of road design on mean speed and standard deviation of speed by road category. CR means Current road design and SER means Self-explaining road design (Kaptein & Claessens 1998).**

### 5.5.4 Conclusions

The results have implications for road design. Road category and driving environment apparently influence drivers' speed choice. Consequently, it is important that road design gives correct impression of the road category to drivers, and thus enhances their chances for appropriate choice of speed. In practice, road categories are defined by a set of characteristics on several dimensions such as lane width, road surface, delineation, and elements along the road. Due to local circumstances some of the pre-defined characteristics can not always be applied in a given traffic situation. The present results suggest that providing redundant information does not help the individual road users since they only use a few of the available characteristics for individual road classification. Correct classification by road users can only be enabled if the few dimensions that are used by road users always provide consistent and correct information on the type of road. It appears to be best to identify those dimensions such that differences among categories are learnt most easily. Only specific dimensions such as lane width and the presence of bicycle lanes seem to affect drivers' speed choice directly.



To meet drivers' expectancy consistently, a limited set of road categories with each maximally distinguishable from each other by the road users is needed, with appropriate speed levels dependent on the function of the road and a road environment design that is in accordance with this function. The results indicate that a more systematic application of road design elements result in a subjective road categorisation that is more in correspondence with the official road classification and in a reduced variation in driving speeds within a given road category.



## 6 INNOVATIVE SPEED MANAGEMENT TOOLS

### 6.1 BACKGROUND

Vehicle speed is a key factor in road safety and the decisive part in the road-vehicle-human system is the driver who makes the speed choice. The driver's actual speed choice depends partly on the environment and the actual situation in which he is driving and partly on his intention to keep (or not keep) the speed limit, and on his speed habits. Intentions are influenced by subjective risks of being involved in an accident or being caught for speeding. Safe driving requires the ability to make accurate estimates of absolute and relative speed. Drivers may speed for a variety of reasons such as impaired judgement through alcohol and other drugs or they may simply be in a hurry. Many drivers maintain a speed in excess of the posted limit but below a level at which they believe they will be cited. In addition, drivers may engage in inadvertent speeding whereby they fail to realise they are travelling too fast for the environment (e.g. junctions, curves, motorway exits, construction zones). Finally, drivers who have been driving at a high speed for an extended period (e.g. on a motorway) may become habituated to the speed and overestimate the degree by which they are lowering their speed when arriving zones where slowing down is required (*Várhelyi 1998*).

Traffic safety work is generally concentrated on making the driver's task easier, by providing better roads and cars and by improving the driver's skills. This strategy does not take into consideration that driver tend to react to changes in the traffic system (in roads, vehicles or in their own skills) in a way which eliminates or reduces the potential safety effects. A changed driving environment, resulting in an increase in the driver's sense of subjective safety, can lead to behavioural modification (e.g. faster driving), which may diminish the safety benefits of the improvement (*Várhelyi 1998*).

Car manufacturers develop and equip new vehicles in increasing amounts with advanced systems based on new technology (ABS brakes, anti-skid devices, airbags, automatic hazard detection devices, UV headlight, etc.). These systems have demonstrated good safety potential – in controlled test situations. Can we be sure that they will have the same effects in real traffic conditions? It is too often assumed that the driver, if he gets the right information at the right time and the opportunity to enhance his safety with the help of the simplified driving tasks, will really use it to improve his safety. Nonetheless, simplified driving tasks can also be used to win more time by driving faster and thereby the safety effect of the system can be reduced. Very little has been done to reduce the proportion of drivers exceeding the speed limit. These observations speak for a system which helps the driver both in the information acquisition and decision-making phase of his speed choice and changes his behaviour in the long-term into positive direction for safety (*Várhelyi 1998*).

Recent technological advances have allowed the application of Information Technology and modern communications to transport issues, often termed ATT (Advanced



Transport Telematics). Tools based on ATT offer flexibility and give broad possibilities to manage speed also in varying conditions like adverse road and weather conditions (e.g. slippery road, fog), in place-, and time related critical conditions (e.g. in school zones), in critical interactive situations with other road-users (e.g. pedestrians crossings). ATT may include equipment in the road environment and/or in the vehicle (*Várhelyi 1998*):

- giving information on actual speed limits
- giving recommendations regarding appropriate speed in critical conditions
- warning the driver of speed errors
- registering inappropriate speed
- preventing the driver from exceeding the current speed limit or the appropriate speed in a certain situation.

The research in project MASTER concerning innovative speed management tools started with a literature and evaluation of various ATT and traditional (non-ATT) methods for reducing driving speed (section 6.2.1). The outcomes of the literature review were used to test the effectiveness of the most promising ATT and non-ATT systems in a controlled environment on a driving simulator (section 6.2.2). In another simulator experiment driver reaction to and acceptance of an in-car speed limiter were investigated (section 6.3.1). In order to investigate driver reaction to an in-car speed limiter in real traffic conditions, field trials in three “regional typical” European countries were carried out (6.3.2).

## **6.2 TRADITIONAL AND ADVANCED SPEED MANAGEMENT TOOLS**

### **6.2.1 Literature study of ATT and non-ATT speed management tools**

The aim of the literature study was to identify the most promising ATT and non-ATT systems for speed management and to build a base for comparative trials in a controlled environment on a driving simulator. The principal findings are summarised below (*Comte et al. 1997*). More detailed assessment of the individual measures and tools is presented in Chapter 7.

#### ***Traditional measures***

Traditional approaches to speed management have concentrated on modifying road and environment related variables (such as traffic calming interventions), and driver related variables (such as enforcement and public awareness campaigns). It is thought that enforcement measures, as well as resulting in reduced speeds, may bring about increased levels of driver vigilance (in the hope that early sighting of police will reduce the likelihood of detection and punishment) and that these increased levels of vigilance will have inherent safety benefits. Visible enforcement, directed towards specific groups of drivers, confined to certain places and administered regularly at times when many of the



passing drivers are commuters, usually results in an immediate reduction in speeding. However, the cost of enforcement is relatively high and even if the necessary funds were available to increase the level of enforcement, there is evidence to suggest that the extent of speed reduction in time and space is very small (*Hauer et al. 1982; Østvik, & Elvik 1990; Teed et al. 1993*).

Public awareness campaigns try to alter public attitudes towards speed (e.g. Kill your speed, not a child). According to *Andersson (1978)*, the problem can be divided into three parts:

- The recipient must be motivated
- The material must clearly communicate to the recipient what informational, attitudinal and behavioural changes are necessary
- The recipient must make those changes.

It seems that many campaigns fail to meet these criteria. The above criteria also rely on the assumption that behavioural change will arise as a result of attitudinal change. This correlation has been shown to be low (*Fishbein & Ajzen 1975*). It has been suggested that information campaigns against speeding are ineffective because speeding is a complex behaviour and to follow the advice may be inconvenient and the benefits not obvious. As with enforcement it is postulated that any possible positive effects may disappear after the campaign has ceased (see e.g. *Hydén & Persson 1986, Järmark 1992*).

Engineering the road and its immediate environment have been shown to have long-term effects on changing driver behaviour (*Russam 1979, Silcock & Walker 1982, Wright & Boyle 1987*). The effects can be lasting in time, however their effect in space mostly ceases outside the vicinity of the measures and driver acceptance is not always high. The most efficient speed-reducing physical measure is the road hump with stable, long-term local effects. Transverse road markings and rumble strips have a good initial effect but this can be short lived. Rumble areas and strips are suitable where accident reports appear to show that drivers were unaware of potential hazards, which may be linked to the speeds of the vehicles.

Isolated measures, such as advisory speed limits, warning signs, gateways, road narrowings and chicanes often have only a small effect on speeds. Chicanes can work well at slowing traffic but their effectiveness is related to the severity of the geometry and care must be taken when access is required for larger vehicles or on bus routes. Throttles or narrowings can be effective, but really only when two way vehicle flows are relatively high so that greater caution is required by drivers. In addition, they may reward aggressive driver behaviour and require adequate signing and marking in advance to avoid becoming a safety problem themselves. It appears that by breaking up the perceived straightness of a road driver speed can be reduced, thus the introduction of a mini-roundabout or changed junction priorities can have a calming effect particularly when linked to other features. The evidence on the effectiveness of curve warning signs and advisory speed signs is contradictory in terms of their effect on speed, but it appears



that signs should justify their presence by specifying the possible hazard or other reason for the required lower speed. Delineation systems are roadway markers that provide the driver with information about the path and demands of the road. However, several studies have indicated that negative safety benefits may accrue as they could encourage increases in speed due to overconfidence on the part of the driver and improved visibility.

Combinations of traditional measures often work well together where individually they may have little effect (e.g. *Pyne et al. 1995*). Traffic calming measures should be implemented as part of an overall Urban Safety Management Strategy as they need to be viewed in terms of the whole transportation system. It is also possible that the installation of traffic calming measures on isolated roads causes local diversions onto other roads and thus create accident migration. Traffic calming may have the potential to stem the flow of traffic in local environments, but if the arterial and collector roads are incapable of carrying the excess traffic, there will be no overall gain to the system. Area-wide measures and environmentally adapted through-roads are effective within the implementation area, but compensating effects can arise in the form of driving faster outside these areas.

### **ATT systems**

ATT systems for speed management may be divided in three categories:

1. Informative/warning systems aim to influence drivers' speed choice, but leave the decision to them:
  - variable speed limit signs at the roadside
  - speed feedback signs at the roadside
  - informative in-vehicle devices
  - in-vehicle feedback on speed errors
2. Recording systems register speed:
  - automatic speed surveillance
  - in-vehicle speed recorder
3. Intervening tools set the limit in the vehicle and thereby take away the possibility from the driver to exceed the pre-set limit:
  - adaptive cruise-control
  - fixed speed limiters
  - variable speed limiters

The impacts on speed of these systems are described briefly below. More detailed descriptions are provided by *Comte et al. (1997)* and *Várhelyi (1998)*.

**Variable speed limits** are usually employed in dense traffic to improve flow, or adverse weather or road surface conditions to reduce accident risk (e.g. fog or icy road). Several studies have showed that they can be effective. The speed-reducing capacity of variable speed limits appears to be largest if the reason for the current limit is indicated in the form of warning or advice. Furthermore, in adverse conditions drivers usually voluntarily reduce their speed (even without reduced speed limit), and the signs can even increase



speeds if the reduced speed limit is too high for the prevailing conditions (*Comte et al. 1997, Várhelyi 1998*).

**Feedback signs at the roadside** can either pertain directly to an individual driver (e.g. “Slow Down, Your speed is XX km/h”) or to the surrounding general driving population (e.g. “Drivers not speeding yesterday XX%”). The effectiveness of providing feedback to the driver may not be due to the feedback per se, but in its implication of speed enforcement. Feedback has good initial effects, however these might decrease with time as drivers realise that no enforcement is connected with the measure. By the combination of feedback and enforcement speeding can almost be completely suppressed conditions (*Comte et al. 1997, Várhelyi 1998*).

**Informative in-vehicle devices** provide drivers with enhanced information on the actual speed. Experiments with such enhanced information systems have produced mixed results. A head-up display (HUD) speedometer, which gives continually speed information to the driver in his normal field of view, might improve speed behaviour and increase safety as every looking at the conventional speedometer takes on average 1.5 sec which can be dangerous in some situations. Continuous information on the current speed limit can even increase speeds (*Comte et al. 1997, Várhelyi 1998*).

**In-vehicle feedback on speed errors** informs the driver of speed limit violations. It can be visual or auditory. Experiments with feedback on speed errors have shown encouraging results, with significant reductions in the proportion of speeders. However, there are differences in the operating modes and installations of the tested in-vehicle feedback systems, and the effect on speeds and driver acceptance in these experiments varied respectively. Furthermore, there is little information on the long-term effects on speed (*Comte et al. 1997, Várhelyi 1998*).

**Automated speed surveillance** by speed-cameras is much more cost-effective than manual surveillance, it increases the objectivity of the enforcement, and simplifies or even makes court procedures superfluous. Several studies have demonstrated that automatic speed surveillance is effective for improving compliance in traffic. The cost-effectiveness of the system is significantly improved if the owner of the vehicle can be held responsible for speeding offences compared to the practice where the driver has to be identified from the photo (*Oei 1998, Comte et al. 1997, Várhelyi 1998*).

**In-vehicle speed recorder** is a clock-driven tachograph recorder, which provides a permanent record of such vehicle functions as speed, distance travelled, etc. In an experiment in the USA tachographs were installed in 224 police cars during 1976-77. Speeds were reduced both when driving with and without emergency lights, and injury accidents were virtually eliminated. The effects were most apparent drivers were given regular feedback on their tachograph discs. The officers, after a short period of resistance, accepted the system as a helpful part of their job and most of them supported the recorders as accident prevention tools (*Larson et al. 1980, Várhelyi 1998*).

**Adaptive cruise-control (ACC)** is a comfort system which helps the driver to maintain his speed on a pre-set level. It can recommend appropriate speeds or adapt speed



automatically to changes in speed limits. AICC (Autonomous Intelligent Cruise Control) can detect vehicles ahead and recommend or adapt the speed automatically in such a way that a safe distance is kept from the vehicle ahead. In the first place it is not a speed limiter, but aims at making speeds more homogeneous. ACC has limitations: it cannot detect stationary objects, its braking capacity is limited and the driver has to intervene, and it works only within a certain speed interval. ACC could give rise to harmful behavioural adaptation in various forms (*Comte et al. 1997, Várhelyi 1998*).

**Fixed speed limiters** are currently obligatory in heavy trucks in many European countries. They prevent the use of speeds higher than 5 to 10 km/h above the vehicle type specific speed limit, which is 80 or 90 km/h in most countries (*Draskóczy & Mocsári 1997*). In addition, some car manufacturers have limited the top speed of their cars to 250 km/h.

**Variable speed limiters** can be manual or automatic. The driver can set the speed limit of manual speed limiters and change it according to the prevailing speed limit, for example. He can also disengage the limiter entirely. Variable speed limiters are meant to be compulsory and they receive the signal that set the speed from external sources (e.g. transmitters at the roadside or via satellite navigation system). If the speed limiter is to give significant safety improvements it must work automatically and be compulsory. Such speed limiters, when installed in all vehicles, can prevent virtually all speeding (*Comte et al. 1997, Várhelyi 1998*). This would reduce the number of injury accidents by between 19 and 34 per cent (*Várhelyi 1996*). The impacts of variable speed limiters on driving speeds are described in more detail in Section 6.3.

Ideally an ATT-system is designed in such a sophisticated way that drivers learn to appreciate the system so that there is a minimum of warnings and recommendations executed and almost never any intervention for acute safety reasons. In general, little resistance is to be expected against the introduction of informative measures. Presumably, it will be different with recording systems (because of implications of the “big-brother-sees-you” dread) and intervening measures which are believed to restrain the action by the driver. However, there is a difference between attitudes based on expectation and attitudes based on experience (*Levelt 1997*), hence acceptance can change after trying out a device.

Real time information on appropriate speeds seem to be important for drivers. A survey among drivers in the USA identified and scored the relative priority of travellers’ needs of Advanced Information Systems. Among 21 systems on trip planning, traveller advisory, traveller services, safety & warning, route guidance and emergency services the highest relative priority was given to “mayday medical emergency service” followed by “warning for appropriate speed limits for the prevailing condition” and “collision warning” (*FHWA 1997*).





### 6.2.2 Simulator study of ATT and non-ATT speed management tools

A simulator experiment was carried out influenced by the findings of the literature review described in Section 6.2.1. A variety of the most promising ATT and non-ATT systems were selected and their effectiveness tested in a controlled environment on a driving simulator. The experiment is described in detail by *Comte (1998a)*. The principal findings from the experiment are summarised below (*Varhelyi 1998*).

In the simulator experiment (Figure 22) drivers encountered curves (radius 100 or 200 metres) in a simulated network of roads that were either treated with one of four implementations or untreated. The four systems employed the following measures:

- Transverse bars (Bars),
- Advisory speed signs at the roadside (VMS),
- In-car visual advice display (In-car),
- In-car automated speed control (SL).

These systems are described in more detail in Appendix 4.



*Figure 22. The Leeds driving simulator (Comte 1998a).*

A control condition was included to serve as a behavioural baseline. Thirty test drivers were involved in the experiment.

It was hypothesised that by providing information and speed advice to the driver, speed would be reduced on the treated curves. In addition it was thought that the different



systems would be variable in their effectiveness. It was also anticipated there might be negative effects of the systems such as increased distraction and mental workload.

Driving behaviour was measured in terms of curve approach and negotiation, using variables of speed and heading and their derivatives. Each participant completed five experimental routes, the ordering of which was balanced. Work load measurements were administered with help of NASA-RTLX method after each experimental route. Performance measures were taken that related to both curve approach and negotiation. Optimal performance was defined as having the following characteristics:

- controlled and timely braking on approach to curves
- large percentage of speed reduction completed before curve entry
- minimal disruption to steering performance in the presence of a novel system
- curve negotiation speed reflecting advisory speed
- minimal behavioural adaptation on straight sections of road

Of all the systems, as would be expected, automatic speed control surpassed all the other systems in terms of effectively reducing speed on approach to curves, as illustrated by Figure 23, Figure 24 and Figure 25. Automatic speed control had also positive effects on lateral control in curve negotiation. In terms of user acceptability, however, this system was least liked.

All the feedback systems significantly reduced speeds when activated (although not as effectively as the automatic system), in the order of approximately 6km/h. However, there were very few differences between the advice systems. The provision of information was particularly effective in smaller radius curves. This was a hypothesised result as the advisory speed for these curves was radically different to the speed environment immediately preceding them. It appears that the provision of advice, in any format, could be effective in reducing speeds. The VMS sign was particularly effective in lowering speeds early on in the approach to the curves, probably due to early detection of the sign by the roadside. However, this early advantage was not maintained, and eventually paralleled the speed reduction curves of the other advice systems.

What is not clear from this experiment is how these advice systems perform over time (and distance). In some previous studies of this nature there has been demonstrated reductions in speed, only to be followed by a subsequent increase again. These sorts of novelty effects are important to establish in terms of cost/benefits analysis, as any initial benefit may be lost over time.

This experiment was also able to demonstrate that there were no obvious adverse affects of providing information in terms of driver distraction and workload. It is important that evaluations of information provision include such an assessment, as any possible safety benefits gained from reduced speed may be outweighed by driver distraction.

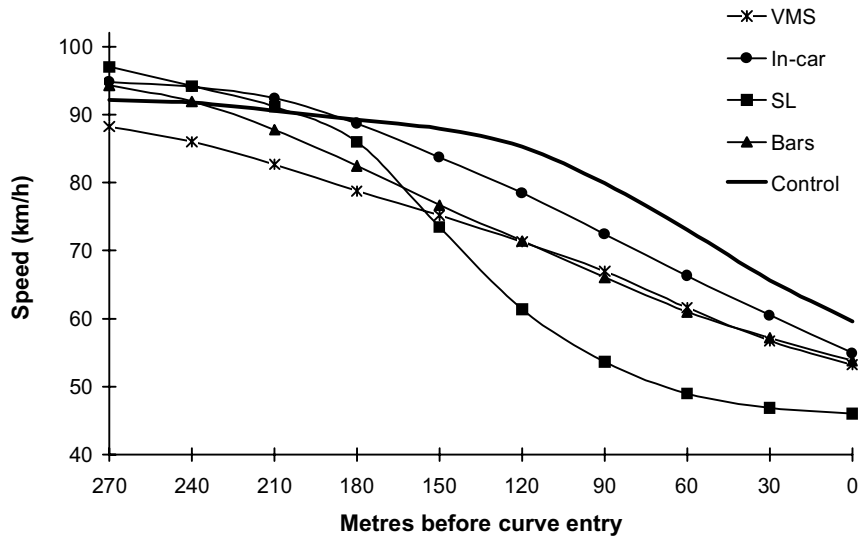


Figure 23. Speed on approach to 100 m radius curve (Comte 1998a).

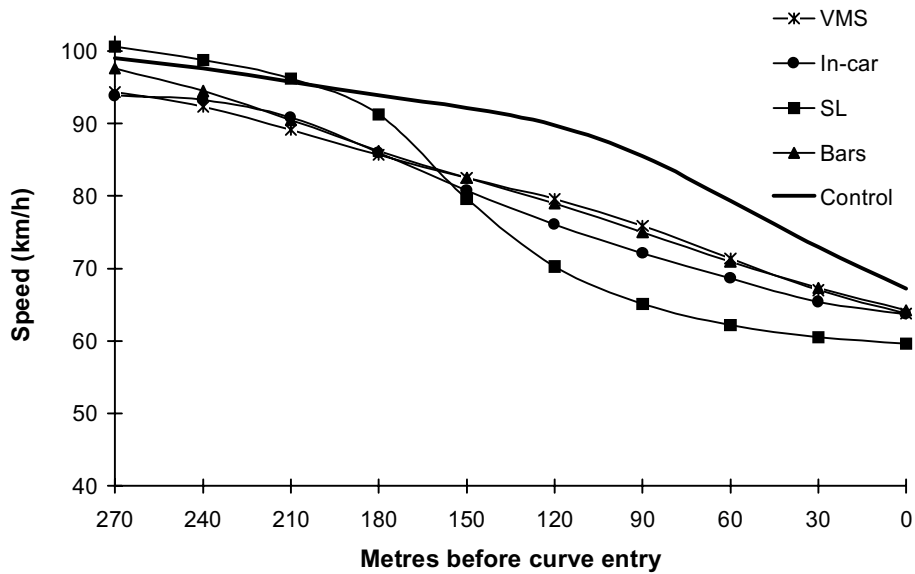


Figure 24. Speed on approach to 200 m radius curve (Comte 1998a).

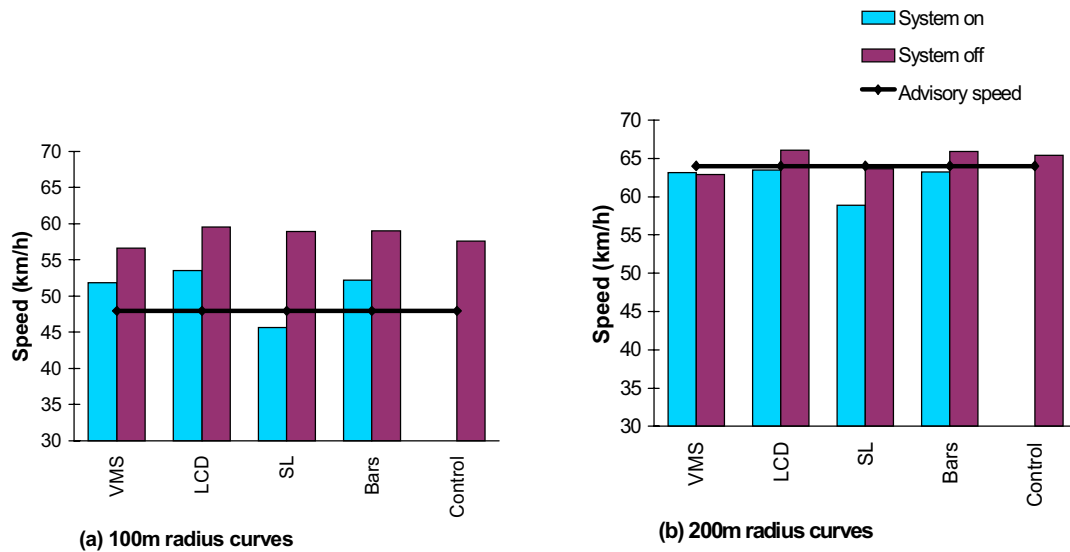


Figure 25. Curve entry speeds (Comte 1998a).

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

## 6.3 IN-CAR SPEED LIMITER

### 6.3.1 Simulator study of in-car speed limiter

A simulator experiment was carried out on driver reaction to and acceptance of an in-car speed limiter, using the same simulator as in the experiment described in Section 6.2.2 (Figure 22). The experiment is described by *Comte (1998b)* and *Várhelyi (1998)*. The principal findings from the experiment are summarised below.

The University of Leeds Advanced Driving Simulator was used to test two in-vehicle speed control systems against an advisory system and a baseline control:

- **Advisory system** provided drivers with a continual reminder of the external speed limit. In addition advisory speeds for any hazardous conditions ahead were also displayed. In this experiment drivers were warned they were approaching a sub-standard horizontal curve and the appropriate advisory speed was displayed by the system. In addition, a message warning of fog was displayed and again the appropriate advisory speed was displayed by the system. The advice was provided via an in-car display situated on the dash board.
- **Fixed system** automatically limited the car to the external speed limit. If the driver travels from a higher speed limit to a lower one, the system automatically reduces the speed of the simulator in readiness for the lower speed limit. Thus the driver will

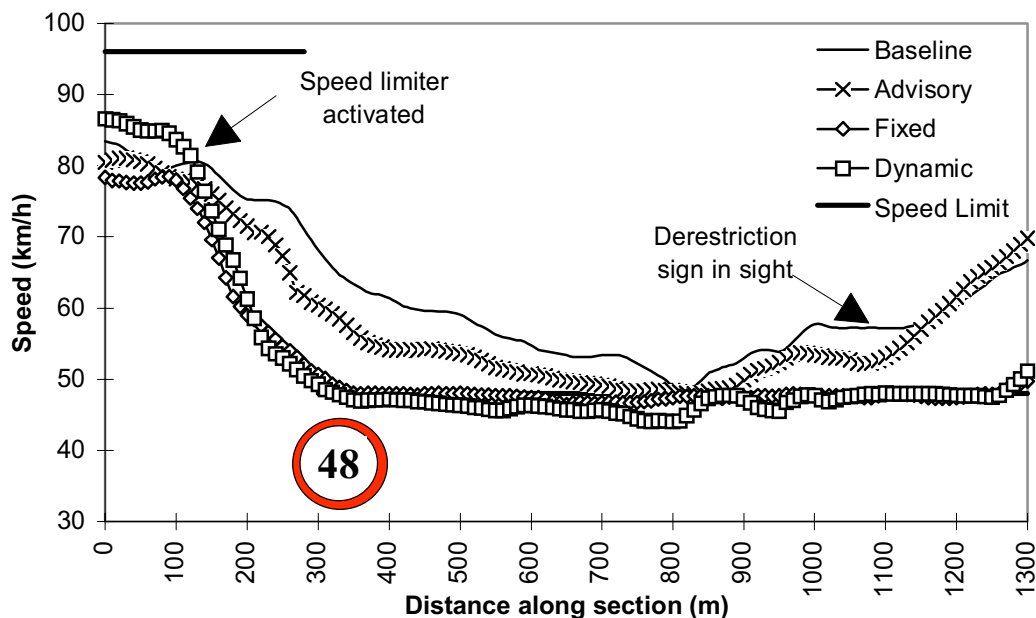


be travelling at the speed limit as they pass the speed limit sign (as is required under traffic law). When the driver is travelling from a low speed limit to a higher one, then the system allows acceleration only after the new speed limit is in operation. See *Comte (1998b)* for more details of the system operation.

- **Dynamic system**, in addition to automatically limiting the speed of the car to the external speed limit, also further reduces speed in hazardous situations. In this experiment drivers were warned they were approaching a sub-standard horizontal curve and the appropriate advisory speed was displayed by the system. The system was activated and drivers could be decelerated if necessary to this advisory speed. In addition, a message warning of fog was displayed and subsequent deceleration to the advisory speed then occurred.

A road environment incorporating urban, rural and motorway scenarios allowed the comparison of the systems across road types. Driver behaviour under the two control systems was compared to that in the advisory and baseline conditions. Behavioural parameters measured include speed and its derivatives, time headway, overtaking manoeuvres, traffic light violations and collision measures. Subjective measures of workload were taken to monitor any possible underload or overload effects, and an acceptability questionnaire was administered to ascertain driver opinion about the systems.

As hypothesised, speed control was successful in reducing excessive speed, particularly in urban areas. The speed profiles showed that without speed control, drivers are susceptible to poor speed adaptation (Figure 26).



*Figure 26. Speed profile through Village 3 (Comte 1998b).*

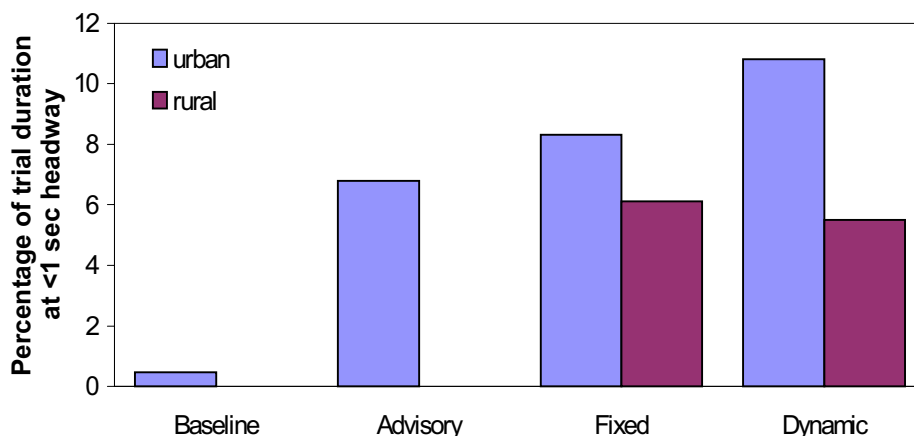


Drivers in both the baseline and advisory conditions do not decelerate to the speed limit of the villages (48 km/h) as they pass the new speed limit, although the advisory system does encourage drivers to reduce their speed further than in the baseline. This is known to be a particular problem in real-life situations where drivers are reluctant to reduce their speed in rural villages. In recent years this problem has been tackled using a variety of ‘village gateway schemes’. Although these can be successful in the short run, the long-term effects are less convincing. The advisory system appears to have some success in reducing speed, although this could be enhanced by providing the information about changes in speed limit before they actually occur. This would provide drivers with the opportunity to decelerate before reaching the lower speed limit.

Speed control also demonstrates other benefits in urban areas such as maintaining lower speeds on curve negotiation and in areas where there are vulnerable road users. Speed variance was also reduced under speed control, suggesting that widespread implementation could have the effect of smoothing traffic flow by reducing extreme speed values.

The advisory system worked almost as well as the dynamic speed limiter in potentially hazardous situations such as sub-standard curvature and poor visibility conditions. Such benefits may be significant considering the proportion of accidents that occur in such conditions.

However, there were also some negative effects of the speed control systems. Firstly, in the case of car following, it was found that those driving with a control system spent more time at shorter headways (Figure 27). This may have been due to impatience, or due to drivers keeping their foot on the accelerator to maintain maximum speed. Such driving behaviour may result in a higher incidence of rear-end collisions, especially if drivers experience a degree of complacency.



*Figure 27. Percentage of trial duration spent at less than 1 second headway (Comte 1998b).*



The incidence of collisions was found to be higher in the fixed condition, independent of speed. This may reflect some degree of loss of situational awareness, such that drivers experiencing the fixed speed limiter were taken out-of-loop, and faced with a critical situation found it consequently more difficult to react in time. This is supported by the relatively late braking that was observed in the fixed condition.

There were no effects of systems on reported mental workload. However it should be noted that any reduction in workload may have been offset by the LCD display, which could have caused additional processing. Future studies should involve the monitoring of eye movements in order to ensure that distraction by the in-car display is not detrimental to the primary task of driving.

The acceptability exercise demonstrated driver's dislike for a system that potentially controls their speed. However it was found that after experiencing such a system, drivers were less negative towards it. As predicted, drivers are more inclined to find an informative system more acceptable, even if its acceptance decreased after experiencing it.

In conclusion, speed control appears reduce significantly mean speed and speed variance. The reduction in speed was especially high at village entries. However these benefits should be considered in the light of potential safety costs such as reduced following distances and possible complacency and loss of vigilance.

### **6.3.2 Field study of in-car speed limiter**

Field trials were carried out in order to investigate driver reaction to and acceptance of an in-car speed limiter. A summary of these trials is presented below. More detailed descriptions are provided by *Várhelyi & Mäkinen (1998)* and *Várhelyi et al. (1998)*.

The trials were carried out in three "regional typical" European countries: Sweden, the Netherlands and Spain. Measurements were conducted with an instrumented vehicle, with unobtrusive observation of driver behaviour, which means that all measuring instruments were hidden and the test drivers were not told about the all measurements that were taken until after the trial. The subjects, 20-24 per country drove two times, once with the "limiter off" and once with the "limiter on" along a test route. The length of the test routes was 20 - 30 km consisting of urban street network, rural roads and a motorway stretch. Different speed limits typical for urban (30 or 50, 60 km/h) and inter-urban roads (70 - 120 km/h) were included. Observed variables were speed, following behaviour, interactions with other road-users, driver workload, and driver opinions.

Separate analysis were made for free speeds, where the driver could choose his/her speed without being obstructed by other traffic (no vehicle in front), and speeds throughout the measurement sections. Actually, drivers were rarely in free driving conditions and therefore the speeds later referred to as "all" practically mean almost the same as driving in platoons.



**Speeds on urban roads**

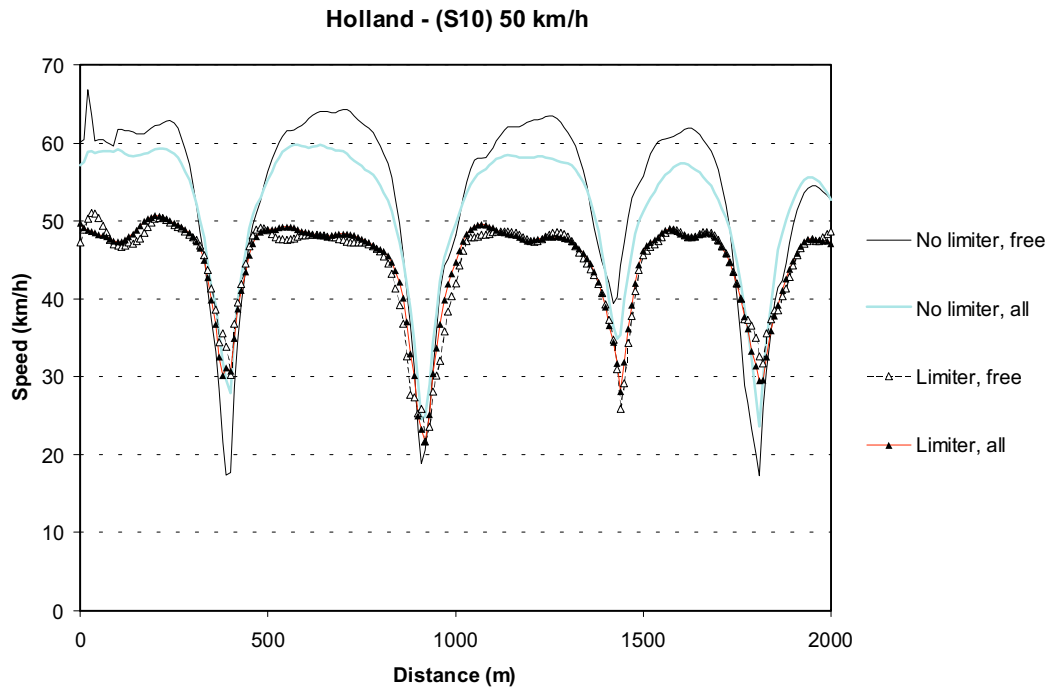
The results showed that the speed limiter reduced speeds significantly on all types of urban road stretches, with speed limits of 30, 40, 50 and 60 km/h (Table 5).

**Table 5. Mean travel speeds by the limiter-on and the limiter-off condition on urban roads (All = normal driving conditions; Free = driving unobstructed) (Várhelyi et al. 1998).**

Speed limit km/h	Country	Mean travel speed (km/h)				Average effect on mean speed (km/h)		Effect on s.d. of speeds (km/h)		Percentage of driving time with speed limiter interference
		All		Free		All	Free	All	Free	
		On	Off	On	Off					
30	Nl	28.0	29.7	28.3	29.6	-1.7	-1.3	-0.1	+0.1	14%
	Spain	18.1	18.5	20.0	16.3	-0.4	+3.7	+/-0	-	18%
	Sweden	30.7	34.7	30.6	35.0	-4.0	-4.4	-3.9	-3.9	26%
	Sweden	24.0	26.1	27.4	31.6	-2.1	-3.8	-1.8	-2.3	19%
	<b>Average</b>	<b>25.2</b>	<b>27.2</b>	<b>26.6</b>	<b>28.1</b>	<b>-2.0</b>	<b>-1.5</b>	<b>-1.4</b>	<b>-1.5</b>	<b>19%</b>
40	Spain	38.4	63.8	39.0	70.7	-25.4	-31.7	-4.8	-0.8	28%
	Spain	39.0	45.8	57.5	80.5	-6.8	-23.0	-9.6	+2.7	51%
	<b>Average</b>	<b>38.7</b>	<b>54.8</b>	<b>48.2</b>	<b>75.6</b>	<b>-16.1</b>	<b>-27.4</b>	<b>-7.2</b>	<b>+1.0</b>	<b>40%</b>
50	Nl	45.5	49.2	51.1	57.9	-3.7	-6.8	-2.9	-3.2	34%
	Nl	47.7	53.8	48.9	53.9	-6.1	-5.0	-3.5	-3.3	28%
	Nl	31.4	32.3	33.2	36.3	-0.9	-3.1	-1.2	-2.6	13%
	Nl	35.0	36.9	33.6	37.3	-1.9	-3.7	+0.8	+2.7	15%
	Nl	43.0	45.3	44.6	45.4	-2.3	-0.9	-2.1	-4.1	14%
	Spain	29.4	28.8	29.8	30.7	+0.6	-0.9	+2.7	+6.5	9%
	Spain	45.9	48.6	49.0	52.1	-2.7	-3.1	+0.1	-1.5	12%
	Spain	18.6	24.1	27.1	38.4	-5.5	-11.3	-5.1	+10.5	14%
	Spain	39.3	50.1	42.4	57.6	-10.8	-15.2	-4.5	+4.4	3%
	Sweden	42.0	44.1	42.5	44.3	-2.1	-1.8	-1.4	-1.5	16%
	Sweden	46.1	50.3	46.0	50.5	-4.2	-4.5	-3.0	-3.0	17%
	Sweden	47.6	53.3	47.4	54.0	-5.7	-6.6	-4.8	-5.0	22%
	Sweden	47.2	50.4	46.9	51.1	-3.2	-4.2	-2.4	-2.0	20%
	Sweden	38.7	38.0	39.4	39.2	0.7	0.2	+/-0	+0.1	6%
	Sweden	41.3	39.2	42.9	41.3	2.1	1.6	+1.6	-2.1	6%
<b>Average</b>	<b>39.9</b>	<b>43.0</b>	<b>41.7</b>	<b>46.0</b>	<b>-3.0</b>	<b>-4.3</b>	<b>-1.8</b>	<b>-0.3</b>	<b>15%</b>	
60	Spain	55.5	62.4	57.8	70.3	-6.9	-12.5	-6.4	-5.1	26%

An example of speed profiles on an urban test road section is presented in Figure 28.





*Figure 28. Mean speeds by the limiter-on and limiter-off condition in a 50 km/h street in the Soesterberg area, the Netherlands (All = normal driving conditions; Free = driving unobstructed). Section 10 = a section including four intersections) (Várhelyi et al. 1998).*

### **Speeds on rural roads**

On rural stretches the speed-reducing effects were only significant on 70 km/h roads in Sweden. On the other rural road stretches (with speed limits of 80 and 90 km/h) no significant effect could be found, which might be due to the traffic situation on these roads with frequent platoon driving (Table 6). However, the limiter eliminated effectively the momentary high speeds.



**Table 6. Mean travel speeds by the limiter-on and the limiter-off condition on rural roads (All = normal driving conditions; Free = driving unobstructed) ) (Várhelyi et al. 1998).**

Speed limit km/h	Country	Mean travel speed km/h)				Average effect on mean speed (km/h)		Effect on s.d. of speeds (km/h)		Percentage of driving time with speed limiter interference
		All		Free		All	Free	All	Free	
		On	Off	On	Off					
70	Sweden	65.6	69.5	65.7	69.4	-3.9	-3.7	-3.6	-3.9	21%
	Sweden	67.0	71.8	67.1	72.2	-4.8	-5.1	-4.3	-4.4	23%
	<b>Average</b>	<b>66.3</b>	<b>70.6</b>	<b>66.4</b>	<b>70.8</b>	<b>-4.3</b>	<b>-4.4</b>	<b>-3.9</b>	<b>-4.1</b>	<b>22%</b>
80	Nl	73.6	72.5	74.5	74.5	+1.1	+/-0	-4.3	-2.6	16%
	Nl	69.2	66.3	70.1	68.5	+2.9	+1.6	-2.0	+0.1	8%
	Nl	66.3	63.0	71.5	69.0	+3.3	+2.5	+2.5	-2.2	9%
	<b>Average</b>	<b>69.7</b>	<b>67.3</b>	<b>72.0</b>	<b>70.7</b>	<b>+2.4</b>	<b>+1.4</b>	<b>-1.3</b>	<b>-1.6</b>	<b>11%</b>
90	Spain	56.8	59.0	60.7	70.1	-2.2	-9.4	+5.7	-	3%
	Sweden	82.0	83.5	84.5	84.0	-1.5	+0.5	+2.4	-6.1	18%
	<b>Average</b>	<b>69.4</b>	<b>71.3</b>	<b>72.6</b>	<b>77.1</b>	<b>-1.9</b>	<b>-4.5</b>	<b>+4.0</b>	<b>-6.1</b>	<b>10%</b>

### Speeds on motorways

The motorway stretches were near the city areas and consequently rather busy. For this reason the overall mean speeds remained clearly under the posted limit and the limiter had in most cases not a very great effect on mean travel speeds (Table 7). However, also here the momentary high speeds were at some points reduced by 10 to 15 km/h.

**Table 7. Mean travel speeds by the limiter-on and the limiter-off condition on motorways (All = normal driving conditions; Free = driving unobstructed) ) (Várhelyi et al. 1998).**

Speed limit km/h	Country	Mean travel speed km/h)				Average effect on mean speed (km/h)		Effect on s.d. of speeds (km/h)		Percentage of driving time with speed limiter interference
		All		Free		All	Free	All	Free	
		On	Off	On	Off					
120	Nl	99.7	95.1	99.8	105.0	+4.6	-5.2	-1.4	+3.8	13%
120	Spain	106.8	110.2	106.1	110.4	-3.4	-4.3	-2.9	-5.8	14%
110	Sweden	102.0	101.6	102.9	104.5	+0.4	-1.6	-2.1	+0.7	18%
	<b>Average</b>	<b>102.8</b>	<b>102.3</b>	<b>102.9</b>	<b>106.6</b>	<b>+0.5</b>	<b>-3.7</b>	<b>-2.1</b>	<b>-0.4</b>	<b>15%</b>



### **Other impacts**

Approaches to roundabouts, intersections and curves were also effected by the limiter causing somewhat smoother approaches in terms of deceleration. This study does not lend clear support to the earlier observations that turning speeds are higher when driving with the limiter on. The speeds in turns in the limiter-on conditions were more often lower compared to limiter-off conditions, however, the differences were not statistically significant. The speed limiter also decreased the variation of speeds clearly thus reducing sudden decelerations. This indicates that if cars in greater volumes were equipped with speed limiter traffic flow could be smoother.

The recorded number of the limiter interferences by driver shows, that practically every subject exceeded the posted limit at some point. Some drivers at all times and the others only occasionally. The duration of the interference also shows great differences. At some sites and for some drivers the duration of limiter interference lasts only a few percent of the driving time, while some other sites, driving conditions and drivers cause the limiter to work even half of the travel time (Tables 5, 6 and 7). Usually in free driving conditions the role of the interference function of the limiter was accentuated - as might be expected.

Travel times increased by between 2.5% and 8.9% depending on the country. The difference in the combined data of the three countries was statistically significant.

Time-gaps in car following situations increased slightly in the speed interval between 30 and 50 km/h indicating that following behaviour became safer when driving with the speed limiter with less tendency to follow at short gaps. On the other hand, on rural roads in the speed interval between 70 and 90 km/h time-gaps decreased which indicates a less safe following behaviour.

Behavioural observations did not show any negative adaptation effect in terms of incorrect giving-way behaviour towards other road-users. The proportion of pedestrians, cyclists and cars who received priority did not change when driving with the speed limiter compared to driving without.

A subjective measurement of the test drivers' workload with the help of RTLX method showed a significant increase in one of the six reported workload aspects, namely frustration level, when driving with the speed limiter compared to driving without. The change in this aspect of workload, however, may be expected when first driving with a new equipment which interferes with the normal driving behaviour.

The most frequent comment after testing the speed limiter was that "*one must be able to accelerate in emergency situations*" and the most often mentioned "emergency situation" was overtaking. This concern might have some ground on rural roads in a scenario with a mixed fleet of equipped and non-equipped vehicles where overtaking is more common. However, in a scenario where all cars are equipped and move in a smooth traffic flow the need to overtake probably decreases significantly. This is reflected in the second most frequent comment that the speed limiter would be



“*useful/ideal*” when all vehicles are equipped. In today’s traffic – as one of the subjects expressed – the driver is under “*strain due to the pressure of knowing that the rest of vehicles aren’t using it*”. In a scenario where all vehicles are equipped there is no reason for such strain. The third most common comment was that speed limiter is “*a good idea/works best (but only) within built-up areas*”.

Before the test drives, a “*device in the vehicle preventing the driver from exceeding the speed limit*” was pointed out as the best method by 18%. After the test drives 30% thought that speed limiters should be *mandatory* in all cars and 59% thought that such a system should be *self operated*, while only 10% were completely against the idea of a system with speed limiters in all cars. This finding indicates that acceptance of the speed limiter device increased after trying it out in the field. Half of the test drivers said that they would voluntarily install a speed limiter in their car (if it did not cost them anything) and half of them answered no.

National differences were found:

- Dutch drivers reported more significant *increase in frustration level* when driving with speed limiter than the subjects in the other two countries;
- b) a larger share (23%) of Dutch drivers were against the idea of automatic speed limiting than in the other two countries;
- c) on the other hand, in the Netherlands a significantly larger group (59%) agreed entirely with the idea of automatic speed limiting *in poor visibility* than in the other two countries;
- d) while in Spain the majority (70%) answered that they would *not install a speed limiter* in their car, in Sweden the majority (62%) answered yes and in the Netherlands it was even between yes and no answers;
- e) while in Spain the overwhelming majority (80%) agreed partly or entirely with the idea of automatic speed limiting *in darkness*, in the other two countries the majority were doubtful or disagreed entirely.

## **Conclusions**

The results of the field study study are best generalised to conditions when travelling in metropolitan areas, close to urban areas and inside towns and cities. There were hardly any conditions in which drivers could drive longer periods of time freely choosing their speed level. On the other hand, a great deal of travelling in Europe takes place in conditions similar to this experiment. The results of the trial should be interpreted as short-term effects. Drivers need time to get used to the equipment and the time available for the test drives was limited to 30-40 minutes per driver per condition (Várhelyi 1998).



## 7 CURRENT KNOWLEDGE OF SPEED MANAGEMENT MEASURES AND TOOLS

In this Chapter different speed management measures and tools are briefly described and assessed with respect to their impact on speeds, other significant impacts and cost-effectiveness.

### 7.1 ASSESSMENT CRITERIA

In the following sections speed management measures and tools are systematically described and assessed with regard to the following properties:

1. Description of the measure or tool
2. Impact on speeds
3. Other significant impacts
4. Cost-effectiveness
5. Other relevant information

<i>Description:</i>	Provides a description of the measure or tool, including information on the common variations in design and application that may affect its performance.
<i>Impact on speeds:</i>	Describes the effect of the measure on driving speeds, usually mean speed but also speed variation and other speed parameters when information exists. Furthermore, attention is paid to the dependence of the speed effect on, for example, a) type of location, b) initial absolute speed level, and c) initial speed level in relation to the prevailing speed limit. In addition, time and distance halo effects are assessed when relevant.
<i>Other significant impacts:</i>	Means impacts on the environment, cost to road users, and installation and maintenance costs when they are considered important.
<i>Cost-effectiveness:</i>	Provides an estimate of the benefits from the impact of the measure upon speeds, taking into consideration also the distribution of effects in time and space, compared with the resources required.
<i>Other relevant information:</i>	Describes miscellaneous aspects such as accident migration when traffic diverts to other routes to avoid speed-reducing measures. Potential problems with acceptability are also mentioned here when they are considered important.



For more detailed information about the various measures in the next sections, the reader is referred to other MASTER reports, especially *Comte et al. (1997)*, *Draskóczy & Mocsári (1997)*, *Martens et al. (1997)*, *Martens & Kaptein (1998)*, *Oei (1998)*, *Risser & Lehner (1998)*, *Robertson et al. (1998)*, *Robertson & Ward (1998)*, *Várhelyi et al. (1998)*, *Allsop (1998)*, *van der Horst (1998)* and *Várhelyi (1998)*.

## 7.2 INFORMATIVE AND LEGAL MEASURES

### 7.2.1 Posted speed limits

**Description:** Speed limits that are indicated by fixed signs on the roadside.

**Impacts on speed:** Backbone of the present speed management system in every country. Studies on the transition from free to limited speeds on rural roads in the 1970's have shown that speed limits significantly reduce speeds and accidents. Posted speed limits are still effective even though a significant proportion of vehicles usually exceeds them.

**Other significant impacts:** Effects that normally follow from speed reduction: reduced exhaust and noise pollution and vehicle operating costs, increased time costs. In urban areas, however, carbon monoxide and particulate emission may increase with decreasing speeds.

**Cost-effectiveness:** The cost of installation and maintenance is low compared to benefits. The main costs come from increased time costs.

**Other:** Lowering of the posted speed limit by 20 km/h on rural roads typically reduces the mean speed by 3–8 km/h (*Ranta & Kallberg 1996*). A similar effect is likely in urban areas. Supporting the reduction of the posted speed limit by other measures, for example by modifications of the road environment and increased enforcement, can significantly increase its effect on driving speeds.

In residential and other urban areas speed reductions can increase the feeling of safety and the quality of life of residents.

Speed limit signs by themselves do not always guarantee that the desired speed level is reached and in urban areas they have to be supported with physical engineering measures.

### 7.2.2 Variable speed limits

**Description:** Speed limits that are indicated by variable, usually remote-control signs on the roadside. The limit is changed according to e.g. traffic volume, weather and road surface conditions.



**Impacts on speed:** Temporarily reduced speed limits can have a small but significant downward effect on the mean speed, and also significantly reduce speed variation. Reduced speed limits are usually used in conditions in which drivers might well reduce speeds anyway, and variable limits thus bring an “extra” reduction.

**Other significant impacts:** Improves the credibility of the speed limit system as speed limits become more flexible and more adequate for the prevailing conditions.

**Cost-effectiveness:** Significant installation and maintenance costs. If variable speed limits are used mainly to reduce speeds in bad driving conditions, the overall benefits can exceed the costs. If, on the other hand, variable limits are used to increase speed limits in ideal driving conditions, benefits can remain well below the costs.

**Other:** Road users often welcome and like variable speed limits and this can result in improved compliance. If variable limits are used not only to reduce speeds in adverse conditions, but also to raise the prevailing speed limit in ideal driving conditions, the overall accident risk may increase.

Technology for the system is available: Seasonal speed limits, used during the winter period in the dark when roads are often slippery, are another form of variable speed limits which have been used in Finland for about ten years.

The language and standardisation problem deserves attention in the case of explanatory signs that are used in connection of variable speed limit signs. The problem is that pan-European travel is expanding, but signs are predominantly text based. The use of pictograms could help to convey the messages, hence there is a need for an international standard for pictograms (for indicating e.g. fog). Action for implementation can be taken by the national road administrations. However, in order to make the variable speed limit more appropriate to the prevailing conditions, with a wider range of speed limit values than those currently in use in a country, changes in the national traffic acts are needed.

### 7.2.3 Vehicle and driver type specific speed limits

**Description:** Maximum legal speeds for certain types of vehicles (e.g. lorries, mopeds, cars with trailers) or categories of road users (typically novice drivers). Cannot be higher than any other prevailing speed limit.

**Impacts on speed:** Probably similar to the impact of posted speed limits. Even though a significant proportion of vehicles (or drivers) may exceed the limit, it still has an important role in reducing speeds.

However, there might be a negative effect by an increase in the variation of speeds in the traffic flow when the speed limit for a given vehicle or driver type is lower than the general speed limit on a road section.

**Other significant impacts:** Reduced vehicle operating costs, increased time costs.



**Cost-effectiveness:** Low installation and maintenance costs. It is not clear which one of the two major effects, reductions in accident costs or increases in time costs, is dominating.

**Other:** Speed limits of lorries are supported by their imperfect braking capability that is significantly worse than that of cars and by the high level of kinetic energy they represent in a crash.

#### 7.2.4 Penalty systems

**Description:** Procedures for handling speed limit violators and consequences for speeding drivers.

**Impacts on speed:** There is no clear dependence between the severity of the penalties for speeding (in terms of the amount of fines, for example) and driving speed. In general, increasing the risk of getting caught is more effective against speeding than increasing the amount of fines. A system where a driver's licence can be cancelled for a fixed period for repeated speeding (three tickets within a year or two, for example) can be effective.

Effectiveness of speed cameras against habitual speeders can depend on the legal requirements for identification of the driver. A system where it is enough to identify the vehicle and the owner can be held responsible unless he/she can prove otherwise is probably more effective than a system where it is necessary to identify the driver from the photo.

**Other significant impacts:** Handling of offences can be laborious and involve lots of manual work by police officers and others.

**Cost-effectiveness:** It is not likely that the magnitude of individual fines has any significant impact on the cost of writing and collecting that fine. Automation of the identification of the speed offender and later handling of penalties would greatly increase cost-effectiveness. In practice this would mean that the owner of the vehicle could be held responsible for speeding.

**Other:** Technology for significant improvement of the cost-effectiveness of penalising speeding drivers is available but this would often mean changes in legislation, especially in the requirements for the identification of the driver.

#### 7.2.5 Speed recommendation signs

**Description:** Fixed roadside signs indicating maximum recommended speed (below the legal speed limit) in sub-standard or dangerous locations, especially curves and intersections.

**Impacts on speed:** They usually have small effects in the beginning, but the effect typically decreases with time. Less effective than speed limit with the same numerical value.





**Other significant impacts: -**

**Cost-effectiveness:** Overall costs small. Consequently, even small speed reductions are sufficient to make the measure cost-effective. However, increased use of recommendations in places where the reason is not apparent for the drivers, would probably reduce their cost-effectiveness.

**Other:** Drivers in general approve of speed recommendations, even though that does not mean that they comply.

### 7.2.6 In-vehicle information

**Description:** Continuous information of the current speed limit provided by in-vehicle display.

**Impacts on speed:** Little or no effect on speed limit compliance.

**Other significant impacts:** In-vehicle display may distract the driver and produce mental overload in complex driving situations. This may increase accident risk.

**Cost-effectiveness:** Poor. The costs for in-car equipment are for the vehicle owners whereas the costs for the infrastructure are public.

**Other:** High driver acceptance. Technology for the system is available and prototypes have been tested.

### 7.2.7 Road-side feedback

**Description:** Feedback can either be individual, pertaining directly to an individual driver (e.g. "Slow Down, Your speed is XX km/h") or collective for the surrounding driving population (e.g. "Drivers not speeding yesterday XX%").

**Impacts on speed:** Feedback has good local effects. However, the initial effects might decrease with time as drivers realise that no enforcement is connected with the measure. Collective feedback is less effective than individual feedback. The effectiveness of providing feedback to the driver may not be due to the feedback per se, but in its implication that it might be combined with enforcement.

**Other significant impacts: -**

**Cost-effectiveness:** Roadside displays are relatively inexpensive. Therefore they are likely to be cost-efficient in potentially hazardous locations. Individual feedback is probably more cost-efficient than collective feedback.

**Other:** Driver acceptance is probably good. Because the effect is limited in distance feedback is most effective in potentially dangerous locations where speeding is frequent. Technology for the system is available.



### 7.2.8 In-vehicle feedback

**Description:** Individual feedback provided by in-vehicle displays informing drivers about their speed, and usually also warning them if they are exceeding the speed limit. In-vehicle feedback can be also auditory.

**Impacts on speed:** Individual feedback has been found to decrease speeding by up to 50%.

**Other significant impacts:** In-vehicle display may distract the driver.

**Cost-effectiveness:** High initial cost. The costs for the in-car equipment will lie on the vehicle owners whereas the costs for the infrastructure are public.

**Other:** Driver acceptance is good. Feedback must be immediate (indicating that an error has just been committed). Auditory feedback is easier to present and increases the mental workload of the driver less than visual feedback. Feedback, if an immediate reaction is required, should be by an auditory or tactile warning. When there is more time to react, a visual warning can be used. Technology for the system is available, however only prototypes have been tested so far.

### 7.2.9 Stop regulation

**Description:** A four-way stop implemented at intersections on local streets to require the drivers on all approaches to stop before entering the intersection.

**Impacts on speed:** Stop regulation has significant speed-reducing effects at intersections.

**Other significant impacts:** A meta-review, based on a large number of studies, concluded that four-way stops reduced the total number of accidents by between 40 and 49% (*Elvik et al. 1997*). On the other hand, they increase time costs, noise and exhaust emissions.

**Cost-effectiveness:** Low installation and maintenance costs that together with the significant speed-reducing effect give good cost-effectiveness.

**Other:** Good driver acceptance (*Hydén 1981*). Stopping behaviour deteriorates slightly with time (*Trafikbyrå 1988*).



### 7.2.10 Education and publicity campaigns

**Description:** Publicity and information campaigns in media and education at school and driving schools about the dangers of speeding.

**Impacts on speed:** There is little direct evidence that education and publicity have a substantial impact in reducing speeds. Partly, this is explained by the fact that it is very difficult to measure the impact. Partly, this can also be considered as an implication that the effect of any one campaign cannot be very big, but this does not exclude the possibility of large cumulative effects.

On the other hand, it is generally recognised that traffic safety education, which should naturally include speed education, is necessary for the system to function at all. Furthermore, information campaigns and publicity can enhance the positive impacts of other measures, e.g. speed enforcement.

**Other significant impacts:** Media campaigns for any specific traffic safety objectives can promote the role of traffic safety in the public decision-making process. Increased interest often means increased resources and attention, and consequently better results.

**Cost-effectiveness:** Costs are relatively easy to measure. Impacts are difficult to assess because they are diverse and extend far into the future.

**Other:** Education and information campaigns are commonly suggested as a counter-measure for any traffic safety problem. It is an easy solution in the sense that there is hardly any opposition to this kind of measures. However, there is usually little reason to expect education and publicity campaigns to be effective, not in the short perspective at least. This concerns also the education and publicity campaigns about the dangers of speed.

## 7.3 MEASURES RELATED TO ROAD DESIGN

### 7.3.1 Speed humps

**Description:** Transverse vertical deflection extending over the width of the road, height typically from 7 to 15 cm, length up to several metres, and shape round or angular. Use restricted to urban roads to support speed limit that is usually 40 km/h or less.

**Impacts on speed:** Humps can be designed (height, length and shape) so that the mean speed at or near the hump decreases to the desired level (for example 30 km/h). By keeping the distance between the humps within certain limits, e.g. no more than 70 m, also the speed between the humps can be reduced almost as much as at or near the humps.

**Other significant impacts:** Can be unpleasant even to occupants of vehicles not exceeding the speed limit. Increases in noise and exhaust emissions may result, especially



in cases where the distance between humps is long enough to make acceleration between humps attractive to drivers. Humps (and the associated speed limit) should be clearly visible to avoid damage caused by unintentional speeding. Accident migration is possible if drivers change their routes.

**Cost-effectiveness:** Depends on the speed reduction, which in turn typically depends on the speed level (mean speed) before installation. It is less likely that humps would be cost-effective on roads where the speeds are typically in the order of 30 km/h, compared to roads where the speeds are around 50 km/h. Furthermore, humps are naturally more cost-effective on busy roads compared to low volume roads. The achievable speed reduction also depends on the design as explained above.

**Other:** Residents usually approve, a proportion of drivers usually opposes. Use on long continuous sections should be avoided to keep acceptability and compliance high.

### 7.3.2 Road cavities (inverted humps)

**Description:** Road cavities are inverted humps with drainage in the bottom.

**Impacts on speed:** Road cavities have significant speed-reducing effects.

**Other significant impacts:** The corresponding accident reduction depends on the magnitude of speed reduction. The measure can be unpleasant to car occupants. It increases noise and exhaust emissions. There is a possible redistribution of traffic to other roads with corresponding accident migration. They have relatively high maintenance costs in the form of keeping the cavities clear from e.g. leaves to maintain water runoff.

**Cost-effectiveness:** Depends on the speed reduction they bring about, which in turn depends on the speed level (mean speed) before installation.

**Other:** The measure, if so designed, fits also on arterial roads with bus traffic (unlike humps), as large vehicles can pass it without inconvenience, while passenger cars have to lower their speed. Driver acceptance is less than for humps.

### 7.3.3 Road narrowings and horizontal deflections

**Description:** Physical narrowing of the carriageway or horizontal deflections that physically restricts use of high speed. Can be supported by structures (e.g. gateways) or vegetation that restrict sight distances and strengthen the perception that the road is narrow. Use typically restricted to support the speed limit of 50 km/h or less in urban areas.

**Impacts on speed:** Wide variation of impacts, probably because of variation in the detailed design and speed level in the before-situation.



**Other significant impacts:** If the width is insufficient for two oncoming vehicles there is a danger that they will compete to arrive first at the narrowing and thereby risk a collision. Accident migration is possible if drivers change their routes.

**Cost-effectiveness:** Depends on the speed reduction, which in turn depends on the design and speed level in the before situation. Traffic volume affects cost-effectiveness, too.

**Other:** There are no general guidelines so far concerning the detailed design of narrowings and horizontal deflections. Therefore, it is difficult to predict how much speed reduction a particular design can produce.

### 7.3.4 Roundabouts

**Description:** Junction type that physically breaks up straight road sections and discourages driving at high speed. The vehicle on the roundabout usually has right-of-way compared to entering vehicles, which also promotes the use of moderate speeds. Furthermore, roundabouts have favourable impact on accident type distribution compared to traditional junctions, for example potentially dangerous front to side collisions at right angles are largely prevented.

Roundabouts can be of the fairly large “conventional” type where the diameter of the central island varies from a few metres to dozens of metres. In mini-roundabouts the central island is smaller, and sometimes the central island is built so that it is possible to drive over it to make it negotiable for large vehicles.

**Impacts on speed:** Roundabouts and especially mini-roundabouts can significantly reduce speeds at urban junctions. The magnitude of the effect depends on the lateral displacement the roundabout forces the driver to, and the level of speeds in the before situation. The magnitude of the speed reduction on links between roundabouts depends on the distance between the roundabouts.

**Other significant impacts:** Roundabouts can decrease total waiting times, noise and exhaust pollution and vehicle operating costs compared to signalised intersections up to a certain traffic volume. On the other hand, they can increase these costs compared to priority junctions with low traffic volumes on the minor roads. Accident migration is possible if drivers change their routes.

**Cost-effectiveness:** Depends on the speed reduction, which in turn depends on the dimensions and speed level in the before situation. Traffic volume and its distribution among the arms affects cost-effectiveness, too.

**Other:** For all roundabouts attention should be given to the needs of bicyclists, motorcyclists and pedestrians in the planning and design phase. Otherwise their accident risk may increase.



### 7.3.5 Village gateways

**Description:** Structures that clearly mark the entrance to a village for the purpose of reducing speeds. They can consist of road narrowings or horizontal deflections, central islands, structures or vegetation that are used to create an image of a narrow road, supplemented by road markings and surface treatments, etc.

**Impacts on speed:** The impact on speeds depends on the actual design and the associated reduction of speed limit. There are examples of successful and less successful installations.

**Other significant impacts:** Village gateways also serve to focus drivers' attention to increased demands of the environment.

**Cost-effectiveness:** Depends on the achieved speed reduction, which in turn depends on the actual design.

**Other:** Gateways have only localised effects and need to be reinforced by other measures if the speed reductions are to be maintained through the villages.

### 7.3.6 Road markings

**Description:** Road markings (usually painted) that actually narrow down driving lanes (e.g. painting of a central island or narrowing the lanes by increasing the width of paved shoulders), or create a visual image that increases the sense of speed, or emphasise the sharpness of a curve. Used typically in sub-standard curves and approaches to intersections or villages. Narrowing the lanes by widening the paved shoulders can be used also on longer road sections.

**Impacts on speed:** Decreasing lane width often reduces speeds on stretches. The impact is probably larger on low standard than on high standard roads. The impact of visual images e.g. on curves can be substantial at first but typically decrease with time.

**Other significant impacts:** Narrowing of lanes at turns and curves can mean that heavy vehicles in increasing volumes cut the curves which increases conflicts with pedestrians and bicycles that use paved shoulder.

**Cost-effectiveness:** Costs are usually low and chances for high cost-effectiveness are therefore often high. The impact on speed, however, varies depending on the characteristics of the road or location and details of the design.

**Other:** Increased use of visual images is likely to reduce their effectiveness.



### 7.3.7 Rumble strips and other road surface treatments

**Description:** Rumble strips are raised transversal road markings (or other road surface treatments) on a lane at (usually) decreasing intervals that cause noise and vibration and increase the sense of speed. They are typically used at approaches to intersections. Other surface treatments can be rough road surfaces that become increasingly noisy or otherwise uncomfortable (stone surfaces) with increasing speed, either on carriageway or shoulder only. Edge lines can be treated so that they generate noise and vibration when driven on.

**Impacts on speed:** Rumble strips have been found effective in reducing speeds at approaches to intersections where substantial speed reductions are required. Noisy or rough bituminous road surfaces can reduce speeds. Tile or stone surfaces, typically used on residential streets, can also be effective. Some studies have found noisy edge lines effective in reducing lane violations but their effect on speed is uncertain.

**Other significant impacts:** Rumble strips and other road surface treatments typically generate noise that can be unpleasant to residents and make them unacceptable on main roads in urban areas and in villages. Noisy surfaces often have an open macro-texture so that they decrease the risk of aquaplaning in wet weather and thus reduce accident risk.

**Cost-effectiveness:** Rumble strips are most likely cost-efficient in many situations. The cost-effectiveness of road surface treatments on driving lanes is less certain. Stone or tile surfaces are expensive and thus less likely to be cost-effective except in special locations where the visual appearance is highly valued.

**Other:** Whatever the macro-texture, it is important that the micro-texture provides a high resistance to skidding.

The effects can decrease with time if the measure is used at sites with a large share of commuting traffic because drivers get used to them.

### 7.3.8 Visibility and visual guidance

**Description:** Decreased sight distances increase uncertainty about traffic situations ahead and thus encourage drivers to slow down. Buildings, fences and other structures can be used to reduce sight distances especially in urban areas. Increased visual guidance works the opposite way. Visual guidance can be increased especially on rural roads by improving the visibility of road surface markings or installing roadside reflector posts.

**Impacts on speed:** Decreased sight distances at intersections are likely to reduce speed in priority directions. Increased visual guidance, on the other hand, has often been found to increase speeds especially on low standard roads.

**Other significant impacts:** -

**Cost-effectiveness:** Highly conspicuous visual guidance is not necessarily cost-effective on low-standard rural roads.



**Other:** Drivers generally welcome improved visual guidance, probably because it seems to make driving easier, especially in darkness.

It is uncertain whether the speed reductions due to reduced sight distances are large enough to fully compensate for the actual risk increase in accident occurrence. Nevertheless, speed reductions generally decrease the severity of accidents.

Even though highly perceivable visual guidance tends to increase speeds, a certain minimum level of guidance (either in the form of centre or edge lines or both) is needed for safe driving.

### 7.3.9 Traffic calming

**Description:** Integrated treatment of areas or stretches of road with various kinds of speed-reducing measures in urban areas. Frequently combined with other measures like road closures, one-way streets and reorganisation of road hierarchy.

**Impacts on speed:** Often substantial, depend on the measures employed, the details of the design and the speed levels in the before situation.

**Other significant impacts:** May cause unexpected changes of routes and accident migration. Decreases noise in residential areas and increases general likeability of the area.

**Cost-effectiveness:** Depends on the design and the amount of attention paid to other than speed-reducing qualities (e.g. aesthetics).

**Other:** Usually has the support of local residents, but some measures (e.g. road closures) can also be disliked by drivers.

### 7.3.10 Environmentally adapted through roads

**Description:** Environmentally adapted roads are aimed at the speed adaptation phenomenon on through-roads in built-up areas by reshaping the environment in a way that the visual impression, together with the changed design of the road, makes the driver lower his speed. An environmentally adapted road comprises several combined speed-reducing measures (village gateways, rumble strips, chicanes, road narrowings, central islands, mini-roundabouts, varying road surface structure and colour, etc).

**Impacts on speed:** Significant, even as high as 15 km/h.

**Other significant impacts:** Safety of vulnerable road-users improves. A meta-review concluded that the measure reduced the number of injury accidents by 30-50% (*Elvik et al. 1997*). Compensating effects can arise in form of driving faster outside these areas. Time costs are increased.





**Cost-effectiveness:** Relatively high installation costs. The effects on accidents depend on the magnitude of speed reduction, and accident reduction is achieved only in case of real speed reduction.

**Other:** While residents and shop-keepers may welcome the measures, car drivers may be negative to them.

### 7.3.11 Self-explaining roads

**Description:** Roads with a design that evokes correct expectations from road users, which in turn leads to correct choices of speed. In practice self-explaining roads mean the introduction of a limited number of road categories so that each road category has a distinct set of characteristics that is clearly different from that of other road categories.

**Impacts on speed:** Generally decreases the variation of speeds. Road modifications that are needed for realisation of the concept may either decrease or increase the mean speeds on particular roads. However, because the possible speed increases are caused by road improvements, they do not necessarily decrease safety.

**Other significant impacts:** It is expected that self-explaining roads significantly improve safety by affecting also other areas of driving behaviour than speed choice. For example, they probably promote correct anticipation. It is likely that the major benefits come from changes in other than speed behaviour.

**Cost-effectiveness:** Effective in reducing variation of speeds. Cost of reconstructing or modifying existing roads can be high, but it is reduced if it is done gradually and systematically in the course of normal road maintenance.

**Other:** A promising concept for a long-term systematisation of the road network.

## 7.4 INTERVENING MEASURES

### 7.4.1 Conventional speed enforcement

**Description:** Roadside enforcement by police patrols where speeds are measured by radar (or by other portable devices) from the roadside. Speeders are then stopped and fines prescribed at site. The speed measurement itself can either be clearly seen by drivers (visual enforcement) or it can be hidden.

**Impacts on speed:** Significant decrease in speed violations, but the effect is limited in time and space. The effects typically last only a few kilometres downstream and disappear within days. Enduring and area-wide effects require frequent enforcement in varying locations. The impact is increased if part of the enforcement is hidden so drivers cannot know in advance where or when enforcement takes place.



**Other significant impacts:** Several policemen are needed at each enforcement site. These resources could be used more effectively in other areas of police work.

**Cost-effectiveness:** Cost is high and cost-effectiveness is low because of the impacts are limited in time and space.

**Other:** Drivers generally approve of conventional speed enforcement. Sometimes hidden enforcement is considered unfair.

#### 7.4.2 Automated speed enforcement

**Description:** Surveillance where the speed measurement and vehicle identification is automated. Speeding vehicles do not have to be stopped at the site. In present applications identification is based on photos of speeding vehicles and drivers. Present technology would enable more efficient identification by compulsory electronic identification devices in vehicles.

**Impacts on speed:** Reduces speeding but the impact is limited in time and space. Effect can be improved by installing a number of camera boxes along the road and by circulating the camera between them. Informing drivers of the surveillance e.g. by roadside signs and individual speed feedback displays by the roadside further improves the effect.

Average enforcement frequency of 12 hours per five days is needed to achieve high compliance.

**Other significant impacts:** Automated enforcement is objective. Lots of extra work is required if identification of the driver from the photo is necessary.

**Cost-effectiveness:** Much more cost-effective than conventional speed enforcement. Cost-effectiveness is further improved if it is not necessary to identify the driver, and the owner of the vehicle can be held responsible.

**Other:** Drivers in general approve of automatic speed surveillance.

#### 7.4.3 Adaptive cruise control

**Description:** There are several types of Adaptive Cruise Control (ACC). ACC helps the driver to adapt his speed to the prevailing conditions, e.g. by keeping the vehicle within a pre-set distance range from the vehicle in front. It can adapt to changes in speed limits, but it does not necessarily mean that speeding is prevented.

**Impacts on speed:** Decreases speed variation between vehicles. Can increase speeds because it may increase drivers' feeling of safety.

**Other significant impacts:** ACC can give rise to potentially dangerous behavioural adaptations, e.g. in the form of decreased situation awareness.



**Cost-effectiveness:** Less cost-effective than in-vehicle speed limiters.

**Other:** ACC is not a speed limiter, but rather a comfort device. ACC works only within a certain speed interval. ACC is not a collision-avoidance system, since in emergency situations the driver himself has to intervene and increase braking.

#### 7.4.4 In-vehicle variable speed limiters

**Description:** The variable speed limiter prevents the driver from accelerating the vehicle beyond the prevailing speed limit. Information of the prevailing limit is transmitted to the vehicle e.g. from roadside transmitters or via satellite, which permits almost real time adjustment of the limit according to traffic, weather and road surface conditions.

**Impacts on speed:** Prevents speeding completely, except in downhill sections where gravity can accelerate the vehicle over the limit. It also decreases speed variation.

**Other significant impacts:** Some negative behavioural modifications may arise in form of shorter headways, shorter accepted gaps at junctions, delayed braking behaviour on approach to junctions, complacency and loss of vigilance.

**Cost-effectiveness:** Providing all vehicles with speed limiters and setting up the system would be expensive, but the benefits are also great.

**Other:** User acceptability varies between countries. On the average approximately one third of drivers approve of compulsory speed limiters and an additional 60% are for a self operated device. Acceptability is greater in urban than rural areas. Gradual introduction of speed limiters would probably cause some problems.

Few other road safety measures have as great potential for improving road safety as compulsory in-vehicle variable speed limiters.

## 7.5 INTERACTIONS

Speed management measures such as those described earlier in this chapter are often used in combinations of two or more measures, according to an area plan or at individual locations. Traffic calming is a typical example of an integrated approach where different measures are applied systematically and physically close to each other. The idea of such approach is to use measures that fit best to the location and make sure that the whole area or road section will be treated effectively. The effects of physical speed-reducing measures are typically limited in space. Therefore, adjacent measures support each other in the sense that when the driver is leaving behind one measure and is tempted to increase speed, the knowledge that another measure is waiting nearby probably dampens this temptation. The areas of influence of two physically successive measures can overlap.

Different measures can also work together. An example of such combination of measures is speed limits and speed enforcement. Other frequently used combinations are, for



example: a) speed enforcement and public information about it, b) roadside sign warning in connection of speed cameras, and c) speed humps or road narrowings combined with road markings. The idea is to strengthen the impact of one measure with the impact of another.

Little is known about the magnitude of the interaction effects. That is understandable because the number of possible combinations of measures is large, and there are great variations in the design of measures.

In principle, if two measures are independent (they do not affect each other) and they are applied simultaneously, their combined effect is similar to the effect when the two measures are applied one after another. For example, if measure 1 reduces speed by 15% and measure 2 by 10%, their combined effect would be  $1 - (1-0.15) \times (1-0.10) = 23.5\%$  reduction. In case the measures are not independent, the total effect is either larger (the measures strengthen each other) or smaller (the measures weaken each other) than in the case of two independent measures.

The example above, however, is not valid in all cases. Many measures are effective only for speeds above certain level. For example, if speed humps are designed to reduce speeds to the level of approximately 35 km/h, they probably have a big effect if the initial mean speed is 45 km/h, but little or no effect if the initial mean speed is 30 km/h. Similarly, even though speed enforcement in general can reduce the mean speed by several km/h, it is probably less effective if the percentage of speeders in the initial situation is exceptionally low.

In practice it is often practically impossible to assess the magnitude of the interactions. In most cases, however, it is probably true that the combined effect of two or more simultaneously applied measures is at least as big as the effect achieved when the more effective of these measures is applied alone. In many cases common sense says that the effect is bigger but there is no simple way of telling by how much.



## 8 RECOMMENDATIONS FOR SPEED MANAGEMENT

### 8.1 BACKGROUND

There are several reasons why further development of speed management is important and why it can be difficult. Some of the main reasons are listed below.

1. Every year about 40,000 people are killed and 1.6 million injured in road accidents in the 15 member states of the European Union. Speed is a contributing factor to the occurrence of a significant number of these accidents. Furthermore, the consequences of accidents generally increase with increasing speeds.
2. Table 1 (page 5) shows that there are great variations in speed limits on similar roads in Europe, even though harmonisation of speeds on similar roads would contribute to fluent and safe flow of traffic. Only in urban areas are speed limits broadly in harmony since the general speed limit is 50 km/h with few exceptions of 60 km/h. On rural roads with mixed traffic the speed limits differ much more ranging from 70 up to 113 km/h for passenger cars. A limit of 80 km/h is most common for both passenger cars and trucks. Motorway is the highest road category with fairly standard qualities across Europe. However, speed limits are quite diverse, ranging from 80 to 130 km/h for cars, and in Germany there is no speed limit on some motorway sections.
3. The basis of the present values of speed limits are vague in the sense that there is little evidence that they reflect the desired levels of speed from the viewpoint of society, or the road transport system. In general, the determination of target speeds (and consequently speed limits) should be based on more explicit criteria and more systematic and comprehensive assessment of all impacts of speed than presently.
4. Drivers frequently exceed the speed limit with up to 80 per cent speeding. It is clear that speed limits themselves are insufficient for keeping speeds at a desired level, even if substantial enforcement is conducted. Speeding occurs especially on low speed urban roads and on motorways. Data from some countries show a systematic increase of actual speed levels over the last years, especially for passenger cars. In general, speeding is becoming more and more frequent phenomenon all over Europe.
5. Because of the difference between private and social costs of driving at a certain speed, drivers' perception of desirable speed differs from that of society. In particular, it is likely that drivers generally underrate accident and environmental costs and overestimate time-savings achieved by fast driving. Consequently, speeds that are optimal from society's viewpoint are generally considered too low by drivers.



6. Consequently, speed management typically has to deal with limitation of speeds. Speed-reducing measures, however, are not very popular among drivers. Therefore, decision-makers, if they pursue maximisation of public welfare, often have to act against general opinion.
7. Reluctance to act against public opinion, even if it would promote the overall welfare of society, may lead to application of generally acceptable speed management measures and tools that are not necessarily effective, instead of efficient but less popular alternatives. It may also be that less proof of efficiency before application is required from generally approved measures than from measures that are considered unpleasant.

## 8.2 BASIC PRINCIPLES

The recommendations presented later in this chapter are based on the following principles:

1. Speed management has two distinct main phases. First, it is necessary to define what are the acceptable or target ranges of speed on different kinds of roads. Second, measures and tools have to be selected and developed that best promote the adoption of such speeds.
2. Speed management on European roads should reflect the objectives of the Common Transport Policy (CTP) (*CEC 1993*). Specifically:
  - (a) The transport sector should function efficiently, safely, under the best possible social conditions and fully respect the objectives of the Community's environment policy.
  - (b) As a general rule all transport users should pay the full costs, internal and external, of the transport services that they consume, even if these costs are in some cases paid by society to assist those in need.
  - (c) According to the subsidiarity principle, it is often best to accommodate for safety requirements at national and local levels. However, even in the absence of exclusive power, transport safety is a matter, which should be addressed by the Community when it is in a position to act usefully.
3. Speed management, especially the determination of target ranges of speed, should pay due attention to the proper balance between the need for national and regional variation on the one hand and the need of pan-European harmonisation on the other hand.
4. Speed management, both the determination of target ranges of speed and the application of measures and tools for the adoption of such speeds, should in general have the approval of motorists and other people.



However, what is considered beneficial and acceptable by the majority of people is not necessarily desirable from society's viewpoint, because of a) the difference between private and social costs, and b) the distributional impacts. Therefore, it is not always good practice to give undue weight to public opinion or acceptability in decision-making regarding speed management.

5. The decisions concerning speed management should be based on explicitly formulated principles (e.g. like those presented in this list), and careful consideration of all possible impacts. The reasoning behind decisions and the weights given to different impacts should be clearly stated.
6. Driving speeds should reflect the socially desirable balance of all impacts of speed, and equitable distribution of these impacts between different groups in the population.
7. Driving speeds should be in harmony with the road environment so that the environment promotes appropriate choices of speed by drivers.
8. Speed management measures and tools should be cost-effective.
9. Speed management measures and tools should exploit advanced technology and promote the relevant industry in the Community, whenever possible and reasonable.
10. Various authorities and other organisations responsible for speed management should have compatible views about the general objectives of speed management, target speeds and measures and tools for adoption of such speeds.
11. Speed management should have a long-term plan to guide the implementation and development of measures and tools.

## **8.3 TARGET SPEEDS**

### **8.3.1 Determination procedure**

According to point one in Section 8.2 the first stage in speed management is to determine appropriate or *target ranges of speed* for each road.

In order to meet the requirements of point 6 in Section 8.2, the determination of target ranges of speed should be based on a comprehensive and systematic assessment of all impacts of speed. The MASTER framework for assessing the effects of speed described in Chapter 4 was developed and tested for such purposes.



### 8.3.2 Practical considerations

Application of the MASTER framework described in Chapter 4 allows, at least in principle, a very precise determination of target ranges of speeds. It is hardly practical, however, to define target speeds more accurately than by rounding them to the nearest 10 km/h, for example.

It is recognised that certain freedom in the determination of target speeds is necessary for consideration of differences in national legislation, enforcement, and the particular social, geographical, demographic and infrastructural peculiarities, and differences in road user behaviour that exist between and within member countries. Nevertheless, there is also a need for harmonisation of speeds and speed limits. The volume of vehicles crossing national borders is increasing and it is essential for the fluent and safe flow of traffic that drivers can trust that there are no large differences between countries in preferred driving speeds or speed limits on similar roads. Harmonisation is needed especially on rural roads and motorways.

It would be helpful for drivers crossing borders if they could deduce on the basis of road category what is the correct level of speed. Currently, however, the categorisation of roads in Europe takes place on a national basis, and there are great differences in categorisation between countries. Motorways are perhaps the only category where such differences are small. Consequently, an important step towards the harmonisation of speeds on European roads would be uniform road classification across Europe.

It seems likely that speed limits will continue to form the backbone of speed management.

### 8.3.3 Harmonisation of speed limits

It seems logical that in general roads that are similar with respect to function, geometry and traffic volumes should have the same speed limit. Adjustments to these limits can then be made, e.g. on the basis of adverse weather, road surface or light conditions, by using variable or seasonal speed limits.

The present speed limits in different countries have been typically chosen without comprehensive consideration or explicit weighting of the impacts. In general, it is hard to find support for the assumption that the present speed limits are approximately optimal for society's viewpoint, or even from the viewpoint of a private road user. Consequently, even if it is agreed that harmonisation of speed limits in Europe is necessary, we can only guess what would be appropriate limits on different kinds of roads. Furthermore, there is much variation presently in what the authorities in different countries consider proper speed limits (Table 1, page 5).

Before making specific suggestions what should be the speed limit on some particular road, or on a road that belongs to a particular road category (that broadly defines the function, geometry and traffic characteristics of that road), it is recommended that a study is conducted where the impacts of speed on a sample of different kinds of roads in





different countries are systematically assessed. The MASTER framework described in Chapter 4 would be a suitable tool for such study.

If the speed limits in Europe were harmonised and the values of the limits were set to reflect the desired balance of the positive and negative impacts of speed from the viewpoint of society, the overall welfare in the Member Countries could be increased, even considerably. For example, significant reductions could be achieved in the number of fatalities and injuries resulting from road accidents. It is not self-evident, however, that great reductions in accidents would be achieved since the values of the speed limits would depend on what is considered "socially desirable". Specifically, the valuation of accidents, travel-time and environmental impacts would probably have a decisive role in the determination of the values of speed limits. Furthermore, drivers would also have to adapt to the new speed limits.

Posted speed limits concern all vehicles. In addition, there are vehicle and driver type specific speed limits e.g. for heavy goods vehicles, coaches, buses, mopeds and novice drivers. In cases where the posted speed limit and other speed limits are different, the lowest of the limits that concern the vehicle and the driver in question holds true. Vehicle and driver type specific speed limits, however, were not especially addressed in the present study. Nevertheless, it does not seem likely that this is a major shortcoming with regard to the overall objectives of the project.

The restriction of the top speed of all vehicles by fixed built-in speed limiters is a possible option for harmonisation of speeds. A necessary precondition is that speed limits are extended also to those sections of German motorways that presently have no limit. The top speed of vehicles should then be set at the highest possible speed limit, or slightly above it to allow for inaccuracies of speedometers that can develop due to change of tyre type or tyre wear, for example. This would efficiently reduce speeding and speed variance on high-speed roads, which would improve safety as shown in Section 3.1. If the maximum speed of vehicles were set clearly above the highest possible speed limits the impacts on speeds and safety benefits would be decreased. It has also been claimed that in-vehicle speed limiters should have a possibility to exceed the limit (temporarily) in order to allow safer overtaking. The safety benefits of such option, however, are arguable since it could increase the number of overtakings and consequently cause more accidents than prevent them.

## **8.4 MEASURES AND TOOLS FOR ADOPTING TARGET SPEEDS**

In this Section recommendations for speed management measures and tools are proposed for four different road categories:

- Urban residential streets
- Urban main roads
- Rural mixed traffic roads
- Motorways



It is clear that different and more detailed categorisation could have been used instead. These four categories, however, cover practically all roads and what is important for the present purpose, they typically differ from each other with respect to road geometry, environment, speeds and safety problems. Where further categorisation is considered practical and useful, it is noted in the text.

According to the principles presented in Section 8.2, the application of measures and tools follows the determination of target speeds. In the following subsections we have therefore presented our view of appropriate speeds and speed limits on different kinds of roads, considering especially safety aspects. It should be emphasised, however, that somewhat different estimates of target speeds could result from comprehensive and systematic assessment of all impacts of speed, which was not possible in this project. Nevertheless, we believe that the possible inaccuracies in the determination of target speeds have critically affected the recommendations for speed management measures and tools for the four road categories presented below.

The recommendations presented in Section 8.4 concern mainly speeds and speed limits in general. Vehicle or driver type specific speed limits are not considered. This should not, however, be a major concern since new suggestions for vehicle or driver type specific speed limits would probably have only a minor role in the overall speed management.

#### **8.4.1 Urban residential streets**

##### **Key features:**

The impacts of traffic and speed management are important for the general quality of life in the area. Pedestrians at least occasionally, and cyclists and moped drivers frequently use the same part of road as motor vehicles. Accident density (per road kilometre) is typically low because of small traffic volumes. Safety of children and other vulnerable road users is decisive for speed management. In accidents car occupants are seldom injured seriously, except in cases involving speeding. The responsibility for speed management lies with local authorities. The speed limit is typically 30 to 50 km/h. There is little or no speed enforcement.

##### **Present speeds:**

Mean speeds in these streets are typically from 30 to 60 km/h. Variation of speeds along the road is low or medium, speeds of single vehicles can occasionally be very high. Speed limit violations are common especially when the speed limit is 40 km/h or lower (*Draskóczy & Mocsári 1997*).

##### **Implications of key features and present speeds:**

The basic speed limit on pure residential streets should be 30 km/h. Lower limits (20 or 10 km/h, or 'walking pace') should be used on short and narrow blind alleys with sight obstructions by the roadside, and on areas specifically designed for slow speeds (e.g. *Dutch woonerfs*). Speed limit 40 km/h can be used if the safety of pedestrians (and



cyclists) is properly taken into account, e.g. by provision of sidewalks or separate paths. Speed limit 50 km/h is normally too high for pure residential streets.

It is often necessary to support speed limits by other measures to reach satisfactory compliance.

In accidents where a car hits a pedestrian, the probability of a fatal injury decreases by approximately 60 per cent as the impact speed of the car decreases from 50 to 40 km/h. A reduction of impact speed from 40 to 30 km/h reduces the risk of a fatal injury by at least 50 per cent (*Pasanen 1991*).

#### **Recommendations for short-term speed management:**

Due to low traffic volumes in these streets, only low-cost measures are cost-effective from a transport economic point of view. However, extra benefits due to improved overall quality of life may justify solutions that would not be considered economic from a purely transport point of view. The most effective engineering low-cost measure is the speed hump (see Section 7.3.1) with stable long-term local effects. Other measures with essential and lasting speed-reducing effect are mini-roundabouts (see Section 7.3.4), stop regulation (see Section 7.2.9) and entry treatments at junctions where residential streets begin. Chicanes, road narrowing and road markings sometimes have only a small effect on speed. Area-wide traffic calming measures (see Section 7.3.9) are effective within the implementation area, but accident migration effects have to be considered outside these areas (*Comte et al. 1997*) and dealt with by complementary measures. For new residential streets low design speeds should be adopted not only in the traditional sense that driving is safe only below a certain speed, but also so that driving above the design speed is effectively discouraged.

#### **Recommendations for long-term speed management:**

Urban areas in general and residential streets in particular would be ideally suited for first large-scale applications of adaptive in-vehicle speed limiters (see Section 7.4.4). One of the main arguments against speed limiters is their low acceptability among motorists. However, results from different trials indicate that in urban residential streets adaptive speed limiters are approved of by a majority of drivers (*see e.g. Comte et al. 1997, Várhelyi & Mäkinen 1998*). Moreover, in these streets residents' opinion should be influential.

#### **Administrative aspects:**

Guidelines or standards are needed to promote consistent speed management within countries and across Europe. Regional differences need to be taken into account in Guidelines.



### 8.4.2 Urban main roads

#### Key features:

On these roads there are often large volumes of motor vehicles, in certain areas mixed with large volumes of pedestrians, sometimes also bicycles. Vehicles turning at junctions and private accesses, and giving way to bicycle traffic and pedestrians cause disturbances in vehicle flow. Accident density (per road kilometre) can be high, serious accidents frequently involve pedestrians or cyclists. Accidents involving only motor vehicles seldom cause serious injuries, with the exception of accidents caused by reckless driving and extremely high speed and accidents of motorcycles and mopeds. The responsibility for speed management usually lies with local authorities. The speed limit is typically 50 km/h. Speed enforcement is limited.

#### Present speeds:

The mean speed is typically over the speed limit in several countries. There is also a large variation of speeds (in space and time). Excessive speeding can be a problem in times of day when volumes are low.

#### Implications of key features and present speeds:

Compliance with the speed limit on these roads should be generally improved. Present speeds are too high especially for the safety of vulnerable road users. In areas with high pedestrian activity reduction of speed limit from 50 to 40 km/h should be considered. At locations where accidents involving pedestrians crossing the road are a specific problem, reducing the speed limit to 30 km/h could be an effective and relatively cheap counter-measure even if structural modifications are used to ensure compliance.

#### Recommendations for short-term speed management:

In order to improve compliance with the speed limit on urban main roads automated speed limit enforcement with the help of speed cameras could be a cost-effective solution (see Section 7.4.2). The effect of surveillance can be significantly increased if combined with information on the speed enforcement both in the mass-media and at the roadside.

Timing of co-ordinated traffic signals can be used to moderate speed provided that the distance between successive signals is not too long.

At locations where the speed limit is reduced to 30 km/h because of pedestrian accidents, compliance to the limit should be ensured by physical measures like elevated pedestrian crossings.

There are few engineering measures that are suitable for improving the compliance on roads with a speed limit of 40 or 50 km/h. Speed humps are not appropriate here, because of the disadvantages caused for heavy vehicles and buses. Road cavities (inverted humps) (see Section 7.3.1) are better for large vehicles and still efficient for passenger cars. However, construction and maintenance costs of road cavities are high.



Mini-roundabouts (see Section 7.3.4) can effectively reduce speeds at junctions and reduce waiting times, noise and exhaust pollution and vehicle operating costs compared to signalised intersections. Low-cost mini-roundabouts are often cost-effective. Road cushions (or speed cushions), which can be passed by large vehicles smoothly, while passenger cars have to slow down, can be used on roads with bus traffic (*Towliat 1998*). Local speed reductions should be supported by other measures such as roundels on the road surface indicating the value of the lowered speed limit. Furthermore, drivers and other citizens should be informed about the effects of the change in speed level (including the effects on accidents, driving time, environment, vehicle operating costs etc.) prior to installing speed-reducing measures.

#### **Recommendations for long-term speed management:**

In-vehicle feedback (see Section 7.2.8) and adaptive speed-limiters (see Section 7.4.4) are sustainable and efficient tools for speed management, especially in urban areas. Large-scale field experiments in different countries and different kinds of urban areas are needed, however, to confirm the positive results from laboratory studies and small scale field experiments.

An intermediate solution is the development of automated speed enforcement (see Section 7.4.2) where vehicles are equipped with electronic identification devices. The system makes possible highly automated processing of consequences. Consequently, it is necessary that the owner of the vehicle can be held responsible for speeding offences, and identification of drivers at site is not required. Furthermore, such devices could be useful for other purposes like collection of parking fees and tracing of stolen vehicles.

Further research on the impacts of speed in urban areas is needed for the assessment of the appropriateness of the present 50 km/h general speed limit. The MASTER framework described in Chapter 4 could be applied for such assessment. And if needed, urban speed limits should be adjusted accordingly.

#### **Administrative aspects:**

Guidelines or standards are needed to promote consistent speed management within countries and across Europe. Regional differences need to be taken into account in the guidelines.

### **8.4.3 Rural mixed traffic roads**

#### **Key features:**

These are usually two-lane roads with large variations in geometry (width, horizontal and vertical alignment) and traffic volumes. There is typically little pedestrian and bicycle traffic except near settlements, but where there is such traffic it often has to use the same part of these narrow roads as motor vehicles. Accidents are not necessarily frequent when related to vehicle kilometres driven or per road kilometre, especially on low-volume roads. The consequences of accidents, however, are often serious, particularly in



head-on accidents, front-to-side collisions at junctions, accidents involving pedestrians or bicycles, and single-vehicle accidents. The responsibility for speed management is often divided between national and local authorities, whereas in some countries rural speed limits are mainly determined at the national level. Determination of speed limits is typically based on national guidelines, but there are significant differences between countries in this respect. The speed limits vary from 70 to 100 km/h. Occasional speed enforcement is done by conventional means (police patrol with radar). The use of speed cameras is increasing even though they are still rare in all countries.

There have been numerous before-and-after studies on the impacts of changes in speed limits on driving speeds and accidents on this type of road, and there is strong evidence that a change of mean speed by 1 km/h typically causes a change of 2 to 3 per cent in the number of injury accidents, and up to twice as big relative change in the number of fatalities (*Andersson & Nilsson 1997, Baruya 1998c, Elvik et al. 1989 & 1997, Finch et al. 1994, Ranta & Kallberg 1996*).

### **Present speeds:**

Speeding is quite common on these roads. The mean speed varies from 70 to 100 km/h but on congested roads it can be lower. The proportion of speeders is often high, especially on low-volume roads with relatively good geometric standards. Speeding is more common on roads with relatively low speed limits compared to roads with higher speed limits. Variation of speeds in space and between vehicles is relatively low (standard deviation of spot-speeds typically approximately 15% of the mean speed, higher on congested roads) (*Draskóczy & Mocsári 1997*). There are indications of large variations between countries in the relation between the speed limit and the mean speed, and also in the proportion of speeders. In one sample of two-lane rural roads in four countries, for example, the proportion of speeders varied from 5 to 55 per cent (*Baruya 1998b, 1998c*). Consequently, there may be significant differences between countries in the guidelines for determining speed limits.

Speed limit violations are frequent on roads through small towns and villages lacking bypass roads.

Speed adaptation to appropriate levels in adverse conditions with increased accident risk (darkness, reduced skid resistance and visibility) is unsatisfactory. On some roads, driving speeds during night-time can even be higher than during daytime.

### **Implications of key features and present speeds:**

The amount of speeding clearly needs to be reduced. This can be accomplished either by speed-reducing measures, or by raising the speed limit. From a traffic safety point of view, increased use of speed-reducing measures seems to be the only sensible solution. Large variations in speed limits and possibly also in national guidelines for setting speed limits indicate that present speed limits (and implicit target speeds) do not always reflect socially desirable or acceptable speeds. Cost-effectiveness of speed management



measures and tools on these roads depends critically on a) traffic volumes and composition and b) the magnitude of speed reductions that can be achieved.

### **Recommendations for short-term speed management:**

In order to lower the speed level on rural roads, road markings (see Section 7.3.6) can be used to increase the sense of speed, especially in sub-standard locations but also decreasing the lane width by increasing the width of paved shoulders could reduce speeds. Furthermore, paved shoulders are important for the safety of pedestrians and cyclists. The cost of the measure is low. However, the cost-effectiveness depends on the characteristics and design of the road and the initial speed level.

On roads where speeding is frequent, to increase compliance, automated enforcement with speed cameras (see Section 7.4.2) should be introduced. In order to increase the efficacy of the surveillance it should be combined with information about the speed enforcement both in the mass-media and at the roadside. Automated speed enforcement is cost effective at the locations where it is implemented, but it can not cover the whole road network.

At locations with frequent speeding and/or high accident frequency, feedback from the roadside (see Section 7.2.7) should be introduced. Roadside displays are relatively inexpensive and therefore cost-effective at hazardous locations.

In order to deal with the speed limit violations on rural roads through built-up areas village gateways at the entrance of the village (see Section 7.3.5) and environmentally adapted through roads within the village (see Section 7.3.10) can be implemented. Village gateways are moderately expensive and their cost-effectiveness depends on the initial speed level at the site. Adapting through roads environmentally is often expensive measure and can involve the rebuilding the whole stretch of road through the village. However, it can be a cost-effective alternative to a bypass road in villages with high volumes of through traffic.

During adverse conditions the speed limit should be decreased accordingly and indicated by variable speed limit signs (see Section 7.2.2). If combined with individual feedback signs from the roadside (see Section 7.2.7) compliance improves significantly. Variable speed limit signs have high installation costs, but their safety potential is high, especially if combined with feedback signs or automated speed enforcement.

### **Recommendations for long-term speed management:**

The concept of self-explaining roads (see Section 7.3.11) should be introduced. A gradual re-design of present roads accordingly would probably reduce the variability of speeds. Importantly, self-explaining roads have other positive impacts on safety such as promoting correct anticipation among drivers.

Further research is needed on the impacts of speed on different kinds of rural road for assessment of the appropriateness of the present speed limits. The MASTER framework



described in Chapter 4 could be applied to such assessment. And if needed, speed limits should be adjusted accordingly.

Further research is needed on in-vehicle feedback (see Section 7.2.8) and adaptive speed-limiters (see Section 7.4.4) in terms of compliance and acceptability on rural roads and to look at their potential in adverse conditions.

#### **Administrative aspects:**

Guidelines or standards are needed to promote consistent speed management within countries and across Europe. Regional differences at the European level need to be taken into account in the guidelines.

### **8.4.4 Motorways**

#### **Key features:**

Motorways are high-standard dual-carriageway roads with grade-separated junctions and for motor vehicles only. Traffic volumes are high. Accident rate is low compared to other road types. Multi-vehicle accidents, often in congested periods and limited sight conditions, are a specific problem. Decisions concerning speed management on motorways are typically made at the national government level. Speed limits are between 90 and 130 km/h, except for parts of the German motorways where there are no limits. Conventional speed enforcement is difficult except during hours of quiet traffic and in good weather and visibility conditions because stopping vehicles at site is a potential safety problem.

#### **Present speeds:**

The mean speed in free flow conditions is typically from 90 to 120 km/h, but often lower in congestion. Speeding is frequent in many countries and increases variation of speeds between vehicles. Vehicle type specific speed limits for lorries and buses are another source of speed variation between vehicles. Variation of speeds along the road is typically small when traffic volumes are moderate. When the traffic volume starts to approach capacity, speed fluctuates and sudden decelerations may occur. Accidents and incidents can cause similar disturbances in the flow and they also often come as a surprise to the drivers.

#### **Implications of key features and present speeds:**

Compliance to speed limits has to be improved. Drivers should be warned in advance of large and often sudden decreases in speed caused by congestion, incidents or accidents. Because of high traffic volumes even high-cost measures and tools can be cost-effective. Nevertheless, critical for cost-effectiveness is by how much, where and how often the measure in question affects speeds. Speed limits on motorways are a potential target for harmonisation, especially on the Trans-European Road Network (TERN). Research is needed to determine the desired levels of speed on different kinds of motorways.



**Recommendations for short-term speed management:**

In order to increase compliance, automated speed enforcement with speed cameras (see Section 7.4.2) should be introduced especially on sections where and during periods when speeding is frequent or extremely high speeds occur. In order to increase the efficacy of the surveillance it should be combined with information on the speed enforcement both in the media and at the roadside. Automated speed enforcement is cost effective at the locations where it is implemented.

Variable speed limits (see Section 7.2.2) together with variable message signs warning drivers of hazardous situations should be installed on busy motorway sections. If these are combined with individual feedback signs from the roadside (see Section 7.2.7) compliance can improve significantly. Variable speed limit signs have high installation costs, but their safety potential is high, especially if combined with feedback signs or automated speed enforcement.

At motorway exits where substantial speed reductions are required rumble strips (see Section 7.3.7) should be installed. Rumble strips are an inexpensive measure and can be cost-effective, but its effects can decrease with time on sites with large share of commuting traffic because drivers get used to them.

The lack of speed limits on some German motorway sections may lead to a waste of resources and unnecessarily high numbers of road accident casualties that concern all citizens of the EU who travel on these roads. Appropriate speed levels for these roads should be determined as described in Section 8.3, and speed limits should be introduced accordingly.

**Recommendations for long-term speed management:**

There is a need for harmonisation of speed limits on motorways. However, further studies are needed to determine desirable levels of speed on different kinds of motorways (with respect to traffic volumes, road geometry, intersection density and design, road surface, weather and visibility conditions).

The concept of self-explaining roads (see Section 7.3.11) should be applied also to motorways.

Motor vehicles should be equipped with top speed limiters set at, or slightly above the highest possible speed limit.

Further research is needed on in-vehicle feedback (see Section 7.2.8) and adaptive speed-limiters (see Section 7.4.4) and their application to motorways.

**Administrative aspects:**

By increasing and developing automated speed enforcement, police manpower could be released from speed surveillance to other duties.



TERN-roads make a clear case for the Community to take action towards harmonisation of speed management. Furthermore, the Community action is needed to restrict the top speed of vehicles.



## 9 CONCLUSIONS

The conclusions from the project MASTER comprise two sets of recommendations, one concerning speed management measures, tools and policy, and the other concerning further relevant research.

### 9.1 RECOMMENDATIONS FOR SPEED MANAGEMENT MEASURES, TOOLS AND POLICY

1. Speed limits on roads of similar classification in different European countries should be harmonised so that road users' expectations are consistent with respect to correct choice of speed irrespective of previous driving experiences in their home country. These speed limits should reflect the socially desirable speeds determined for example with the help of the MASTER framework described in Chapter 4.
2. European guidelines are needed for application of speed management measures and tools on residential and main roads in urban areas and on rural mixed-traffic roads. This would promote consistent and cost-effective speed management both on urban roads, where a wider range of potential alternatives is available and on rural roads where the possibilities for using low-cost physical measures are more limited.
3. Preparations for the introduction of compulsory adaptive speed limiters should be started. Adaptive speed limiters automatically prevent speeding by adjusting speeds according to the prevailing speed limit. The first step could be large-scale field experiments in urban areas in different countries.
4. Road design should be developed in order better to support drivers' correct choice of speed. This could be achieved by hierarchical categorisation of roads into a limited number of categories so that each category has a distinct set of characteristics that is clearly different from that of other categories, according to the principle of self-explaining roads.
5. Automated speed enforcement should be developed further and taken into wider use. To improve the cost-effectiveness of automated enforcement, legislative changes are needed in some countries so that the owner of the vehicle can be held responsible for speeding offences. Cost-effectiveness could be further improved if all vehicles were equipped with an electronic identification device. Such device would be useful also for other purposes, e.g. tracing stolen vehicles and collection of parking fees.
6. Speed management would benefit from the reduction of the difference between the effects of speed on social and private costs. If the cost of increasing (or decreasing) driving speed as experienced by drivers would follow more closely the respective cost to the society, drivers would voluntarily choose speeds that are closer to socially optimal speeds. In principle, this could be achieved by internalising external costs, e.g. accident costs and environmental costs. However, further research is needed to find out if and how this could be realised in practise.



7. Information and publicity campaigns regarding the impacts of speed are needed, with the purpose of giving objective information about all impacts of speed. Such information could increase the public acceptance of speed restrictions that are justified from society's viewpoint. Nevertheless, decision-makers will still need to recognise that popularity is not necessarily a good criterion for speed management policies.
8. Speed limits should be extended to cover all roads in Europe, and the highest possible speed of vehicles should be restricted to the highest speed limit on motorways.

## 9.2 RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is needed in several areas before the recommendations above can be fully, correctly and effectively implemented. Especially, speed management could benefit from research in the following fields:

1. Further research and modelling of the impacts of speed on the various exhaust emissions, noise, vehicle operating costs and time costs is needed so that the speed dependence of different factors would be easier to use in determination of target speed.
2. Present knowledge of network effects of speed management is insufficient, especially in relation to the elasticity between speed and traffic volumes.
3. More information is needed about the use of different kinds of roads in the course of different kinds of journeys for improved assessment of the impacts of different speed management policies.
4. Research on the impacts of changes in speeds on accident occurrence should be continued. Specifically, introduction of speed-limiters and improved speed enforcement are likely to change the form of the speed distributions, and the effects on accidents of such changes cannot be reliably predicted on the basis of previous studies of the relationship between speed and accident occurrence.
5. There are large variations between countries in the monetary valuation of the impacts of speed, especially the value of time, environmental impacts and accidents. Research aiming at more uniform valuation of such impacts would promote harmonisation of speeds.
6. Research is needed to develop commonly accepted procedures for consideration of distributional and equity impacts of changes in speed.
7. The present practice of monitoring the speeds on different kinds of roads differs between countries. Standardisation of collection and reporting of speed data would help in the identification of problem areas in speed management.
8. Further research is needed on in-car systems for intelligent speed adaptation. Potential for adaptation according to weather and road surface condition needs to be



explored. Behavioural adaptation effects need to be investigated. Acceptability and effects on compliance of the various types of system need to be studied, together with their human-machine interfaces in order to make recommendations for design, and for strategies and time-scales of implementation.



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## APPENDIX 1

### A brief description of MASTER Deliverables and Working Papers

#### Deliverables:

- D1 Martens, M., Comte, S. & Kaptein, N. The Effects of Road Design on Speed Behaviour – A Literature Review. MASTER Deliverable D1 (Report 2.3.1). Sent for approval to DG VII in December 1997.

*The report contains an overview of the efficacy of various speed-reducing measures. Advantages and disadvantages of various measures are discussed. Measures that affect driving speed directly are discussed, but special attention is paid to factors that affect driving speed indirectly, i.e. by influencing the willingness to show the appropriate speed behaviour. It is concluded that the latter can be promoted by designing roads so that they are “self-explaining”.*

- D2 Martens, M., & Kaptein, N. Speed Behaviour Before And After Road Design Modifications – A Meta Review. MASTER Deliverable D2 (Report 2.3.2). Sent for approval to DG VII in July 1998.

*The report presents the results of a survey among national road authorities about explicitly evaluated counter measures to reduce driving speed. Combined measures, especially when the image of an entire road section is changed (e.g. 30 km/h zone), had the largest effects. Of the individual measures, direct physical measures such as speed humps and chicanes result in the largest speed reductions. Roundabouts primarily have a positive safety effect. The results were in line with the literature review (D1).*

- D3 Oei, H-L. The Effect of Enforcement on Speed Behaviour: A Literature Study. MASTER Deliverable D3 (Report 2.1.2). Sent for approval to DG VII in June 1998.

*The report presents an overview of research on speed enforcement and its effects on speed behaviour and safety. Different aspects affecting the efficiency of enforcement are discussed. Studies on the impacts of enforcement often lack relevant information, e.g. government policy on speed, law on speed limits and speed, system of fines, enforcement frequency etc. The report concludes with recommendations for efficient and effective speed enforcement strategies.*

- D4 Draskóczy, M. & Mocsári, T. Present Speeds and Speed Management Methods in Europe. MASTER Deliverable D4 (Report 2.1.1). Sent for approval to DG VII in December 1997.

*The report presents the results of a survey on speed limits, speed management and enforcement methods and actual speeds in 10 EU countries and 10 other European countries. There are large variations between countries in speed limits on rural roads. The methods of speed management and enforcement are similar throughout Europe, although there are differences in the frequency of application. Actual speeds usually exceed the speed limit in most European countries, especially in urban areas and on motorways.*



- D5 Kaptein, N. & Claessens, M. Effects of Cognitive Road Classification on Driving Behaviour: A Driving Simulator Study. MASTER Deliverable 5 (report 2.3.3). Sent for approval to DG VII in August 1998.
- The current study investigated the effects of road design characteristics on cognitive road classification and driving behaviour. It was concluded that Self-Explaining Roads (SER) – i.e. roads that promote safe driving behaviour simply by their design – were categorised more in accordance with the official road categorisation than current existing roads. No clear effect on mean driving speeds was found. Yet, results showed that more consistent road design within categories may lead to reduced variation of speeds.*
- D6 Risser, R. & Lehner, U. Acceptability of Speeds And Speed Limits to Drivers and Pedestrians/Cyclists. MASTER Deliverable 6 (report 2.2.2). Sent for approval to DG VII in June 1998.
- The acceptability of present speeds and speed limits to car drivers and vulnerable road users were investigated by interviews in six countries. Both groups think that actual speeds are too high. Car drivers agree that they contribute to the problems with their own speed behaviour. Almost half of both groups think that speed-reducing measures are necessary. However, pedestrians prefer efficient measures that have a direct impact on speeds, while car drivers prefer measures that leave the decision to themselves.*
- D7 Baruya, A. Speed-Accident Relationships on Different Kinds of European Roads. MASTER Deliverable 7 (report 1.1.4). Sent for approval to DG VII in September 1998.
- The report gives a comprehensive description and analysis of flow and speed distributions on a sample of UK and European roads and examines critically the effects of road environment and road geometry on traffic speed and accidents. An accident predictive model is proposed for wider application in the European Union. Despite the likelihood that the model will successfully predict accident frequency for a wide variety of roads it is recommended that, where possible, the model is tested and assessed prior to use in a particular situation.*
- D8 Kallberg, V-P. & Toivanen, S. Framework for Assessing the Impacts of Speed in Road Transport. MASTER Deliverable 8 (report 1.2.4). Sent for approval to DG VII in July 1998.
- The framework is meant for systematic and comprehensive assessment of the impacts of speed. Both the total magnitude of the effects and their distribution are considered. The framework is easy to use and flexible, even though data acquisition may be laborious depending on the aspired accuracy. The application of the framework is illustrated by three real life cases from Finland, Hungary and Portugal.*
- D9 Kaptein, N., van Hattum, T. & van der Horst, R. Categorisation of Road Environments And Driving Speed. MASTER Deliverable 9 (report 2.3.4). Sent for approval to DG VII in September 1998.
- The report presents a series of 5 experiments to investigate how subjects categorise different environments. Subjects were not able to correctly use information from three stimulus dimensions simultaneously. Out of three available dimensions they used only the two that were easiest to learn. In the sixth experiment these road characteristics*





*were linked with subjects' estimates of their driving speeds. Only specific dimensions seem to affect drivers' speed choice directly. Implications for correct classification of different road categories are presented.*

- D10 Comte, S., & Jamson, H. The Effects of ATT And Non-ATT Systems And Treatments on Speed Adaptation Behaviour. MASTER Deliverable 10 (report 3.1.3). Sent for approval to DG VII in May 1998.

*Following a literature study four systems were selected for simulator experiment: transverse bars, in-car advice system, variable message sign and in-car speed limiter. The results of the simulator tests suggest that the provision of speed advice to drivers does result in reduced speed on the approach and negotiation to curves. It seems to matter little exactly in what mode this advice is given to drivers. As would be expected optimal performance is attained under an automatic system.*

- D11 Várhelyi, A., Comte, S. & Mäkinen, T. Evaluation of In-Car Speed Limiters, Final Report. MASTER Deliverable 11 (report 3.2.3). Sent for approval to DG VII in September 1998).

*The report summarises the studies on the effects of adaptive in-car speed limiters on driving behaviour (Working Papers 3.1.1, 3.2.1. and 3.2.2). It was concluded on the basis of simulator and field experiments that in-car speed limiters can significantly reduce speeding and speed variation and improve driving behaviour in critical situations. The results were promising especially in urban areas, where also driver acceptance was highest. Areas for further research were identified.*

- D12 Kallberg, V-P., A., Allsop, R.E., Ward, H.A., van der Horst, R. & Várhelyi, A. Recommendations for Speed Management Strategies and Policies. MASTER Deliverable 12 (report 4.1.1). Revised in December 1998).

*The report describes the scope and present state of speed management and summarises current knowledge of speed management measures and tools. It is recommended that target speeds on different kinds of roads are determined on the basis of systematic and comprehensive assessment of all impacts of speed. Recommendations for the adoption of such target speeds include harmonisation of speed limits, development of road type specific guidelines for the application of different speed management measures and tools, further development and wider use of automated speed enforcement, and introduction of adaptive in-vehicle speed limiters.*

## **Working Papers:**

- 1.1.1 Baruya, A. A Review of Speed-Accident Relationship on European Roads. MASTER Working Paper 1.1.1. Completed in August 1997.

*The report reviews the available research on models relating road accidents to traffic speeds. International data suggest that a 1 km/h reduction in the mean traffic speed on rural roads is associated with an approximately 3 percent reduction in the number of injury accidents, and the effect on fatal accidents is even higher. Further research is needed, however, to find out if the effect of speed varies between road categories. Multiplicative Poisson models and generalised linear modelling (GLM) technique are recommended for the modelling of accident counts.*



- 1.1.2 Baruya, A. Speed-Accident Relationship on Single-Carriageway Roads of UK. MASTER Working Paper 1.1.2. Completed in July 1998.

*This report examines the speed-accident relationship on rural single carriageway roads of England. It gives a comprehensive description and analysis of observed flow and speed distribution parameters. The effects of flow, speed and geometry on accidents on rural roads were investigated. Two models were developed to describe the effects of flow, speed and geometry on the number of injury accidents.*

- 1.1.3 Baruya, A. Speed-Accident Relationship on European Roads. MASTER Working Paper 1.1.3. Completed in July 1998.

*The report gives a comprehensive description and analysis of flow and speed distribution parameters on rural single-carriageway roads in England, Sweden, the Netherlands and Portugal in order to gain a better understanding of their effects on accidents. The relationships derived on the basis of English data (MASTER working paper 1.1.2) were tested using data from other countries and the accident predictive models were further refined for further application in Europe.*

- 1.2.1 Robertson, S., Ward, H., Marsden, G., Sandberg, U. & Hammarström, U. The Effects of Speed on Noise, Vibration and Emissions from Vehicles. MASTER Working Paper 1.2.1. Completed in June 1998.

*The report describes briefly the production processes for noise and emissions. In general the HC emissions reduce with speed and NOx emissions increase with speed. CO and particulates have lowest emission levels at medium speeds. Hard acceleration can significantly increase pollutant emissions. Above 40-50km/h noise increases linearly with speed. Acceleration and braking cause a small (1-2dB) increase in noise. Example estimates for noise and emissions are provided for a limited set of cases of steady speeds.*

- 1.2.2 Robertson S. & Ward H. 1998. Valuation of Non-Accident Impacts of Speed. MASTER Working Paper 1.2.2. Completed in September 1998.

*This report gives information on a range of models to help in estimating the effects of speed management measures on the costs experienced by vehicle users. A description of the impact of speed on journey time together with a worked example is provided. Vehicle operating costs fall to a minimum at about 70km/h and fuel costs at about 60km/h. The valuation of non-accident impacts of speed are described and examples for noise and some exhaust emissions are provided. Areas for further research are identified.*

- 1.2.3 Kallberg, V-P. & Toivanen, S. Framework for Assessing the Effects of Speed. MASTER Working Paper 1.2.3. Completed in December 1997.

*The presented framework enables systematic assessment of the impacts of speed on a) vehicle operation costs, b) travel time, c) accidents, d) pollution, and e) other potential impacts. Both magnitudinal and distributional effects are considered. The framework is easy to use and flexible. The user defines the impact functions and chooses the monetary prices of the effects where applicable. Transparent, systematic and clear presentation of the results is an essential feature of the framework.*



- 1.3.1 Allsop, R. Summary of research area 1: Basis for Appraisal of Effects of Different Levels of Speed. MASTER Working Paper 1.3.1. Completed in September 1998.

*This summary report on Work Area 1 addresses the question “What are acceptable ranges of speeds?” The report gives an overview of the results from Deliverables 7 and 8 and working papers 1.1.1, 1.1.2, 1.1.3, 1.2.1, 1.2.2, and 1.2.3. It is concluded that the climate of opinion of drivers as well as vulnerable road users may well be favourable to speed management to moderate speeds.*

- 2.2.1 Levelt, P. Speed and Motivation: Established And Newly Developed Ideas About the Content of Questionnaires And the Design of Campaigns. MASTER Working Paper 2.2.1. Completed in April 1998.

*The report discusses motivations of road users in regard to how fast they drive and what they think about the driving speed of others. It is concluded that driving speeds are affected by several factors, e.g. a) the speed of others, b) opinions of significant others, c) emotions and moods, and d) personal characteristics. People often feel that it is difficult to control own driving speed, and they also overestimate their own ability to control the consequences of speed.*

- 2.4.1 van der Horst, R. Summary of Research Area 2: Factors Influencing Drivers' Speed Behaviour and Adaptation. MASTER Working Paper 2.4.1. Completed in September 1998.

*This report summarises the findings of Research Area 2 and addresses the question “What are the key factors influencing drivers' choice of speeds?” The report gives an overview of the results from Deliverables 1, 2, 3, 4, 5, 6 and 9 and working paper 2.2.1. It deals with speed enforcement, motivation and acceptability of driving speeds, and road design and cognitive road categorisation.*

- 3.1.1 Comte, S., Várhelyi, A. & Santos, J. The Effects of ATT and Non-ATT Systems and Treatments on Driver Speed Behaviour. MASTER Working Paper 3.1.1. Completed in August 1997.

*The report reviews the relevant literature and various Advanced Transport Telematics (ATT) and traditional (non-ATT) methods of reducing driver speeds. It is concluded that the most successful traditional measures appear to be those which require drivers physically to lower their speed or alter the way in which drivers perceive the road. ATT systems such as speed limiters and adaptive cruise control are promising, but the associated issues of reliability, behavioural adaptation and acceptability merit further research.*

- 3.1.2 Comte, S. Simulator Study on the Effects of ATT and Non-ATT Systems and Treatments on Driver Speed Behaviour. MASTER Working Paper 3.1.2. Completed in January 1998.

*The report describes the driving simulator experiment on the impacts of four different systems (Variable Message Sign, in-car advice, automatic speed control and transverse bars) on curve approach and negotiation speeds. As would be expected, automatic speed control was most effective, but it was also least liked by drivers. The other systems also significantly reduced speeds. It was concluded that the provision of advice, in any format, could be effective in reducing speeds.*



3.2.1 Comte, S. Evaluation of In-Car Speed Limiters - Simulator Study. MASTER Working Paper 3.2.1. Completed in May 1998.

*Two different speed limiters were tested against an advisory system and a baseline control in a driving simulator. Both speed limiters reduced speed, speed variance and speed at hazardous locations. However, the speed limiters also had secondary effects that could compromise safety. These included a higher incidence of short time headways, delayed braking and a higher incidence of collisions. The advisory system also performed well. Drivers found the advisory system more acceptable than the control systems.*

3.2.2 Várhelyi, A. & Mäkinen, T. Evaluation of In-car Speed Limiters: Field Study. MASTER Working Paper 3.2.2. Completed in June 1998.

*The impacts of a variable speed limiter were studied in field trials in three countries using an instrumented car where all measuring equipment was hidden. The results revealed that the speed limiter reduced speeds significantly in free driving conditions, decreased speed variance and approach speeds at curves and intersections. It also increased travel time. The drivers' acceptance of the device increased after the test drive but they still generally felt that speed limiter caused frustration, stress and impatience.*

3.3.1 Várhelyi, A. Innovative Speed Management Tools: Summary Report on Research Area 3. MASTER Working Paper 3.3.1. Completed in June 1998.

*This summary report on Work Area 3 addresses the question "What are the best speed management tools and strategies?" The report gives an overview of the results from Deliverables 10 and 11 and working papers 3.1.1, 3.1.2, 3.2.1 and 3.2.2. Furthermore, recommendations are made for speed management tools and strategies and areas of further research are identified.*



## APPENDIX 2

### Models for mean speed and accidents

#### 1. Models for mean speed and number of injury accidents per year on stretches of single-carriageway rural road in England

The mean speed was found to be estimated in km/h by

$$45.65 \times \exp(0.0065 \times \text{speed limit in km/h}) \\ \times (\text{percentage exceeding the speed limit})^{0.0376} \\ \times (\text{percentage below half the speed limit})^{-0.0637} \\ \times (\text{flow in vehicles/day})^{-0.0152}$$

The number of injury accidents was found to be estimated by

$$1280 \times 10^6 \times (\text{mean speed in km/h})^{-5.95} \\ \times (\text{percentage exceeding the speed limit})^{0.227} \\ \times (\text{percentage below half the speed limit})^{-0.383} \\ \times (\text{flow in vehicles/day})^{0.530} \\ \times \exp(0.071 \times \text{number of junctions})$$

#### 2. Models for mean speed and number of injury accidents per year on stretches of single-carriageway rural road in England, The Netherlands, Portugal and Sweden.

The mean speed was found to be estimated in km/h by

$$31.39 \times \exp(0.0088 \times \text{speed limit in km/h}) \\ \times (\text{percentage exceeding the speed limit})^{0.0744} \\ \times (\text{percentage below half the speed limit})^{-0.0327} \\ \times (\text{flow in vehicles/day})^{-0.0097} \\ \times (\text{length of road in km})^{0.0139}$$

The number of injury accidents was found to be estimated by

$$5.663 \times (\text{mean speed in km/h})^{-2.49} \\ \times (\text{percentage exceeding the speed limit})^{0.114} \\ \times \exp(0.023 \times \text{speed limit in km/h}) \\ \times (\text{flow in vehicles/day})^{0.748} \\ \times (\text{length of road in km})^{0.847} \\ \times \exp(0.038 \times \text{number of junctions}) \\ \times \exp(-0.056 \times \text{road width in metres})$$



## APPENDIX 3

### Application of MASTER framework for assessing the impact of speed

In the following the application of the framework is illustrated by a real life case from Finland. The emphasis is on the description of the results. The presentation is based on a paper by *Toivanen & Kallberg (1998)* where also the phases of the application process itself are described generally. A more detailed description is presented in *Kallberg & Toivanen (1998)*.

#### *Case: Extending the wintertime speed limit to semi-motorways<sup>1</sup> in Finland*

Presently, a major part the trunk road network in Finland (10,100 km out of 13,070 km) is subject to a lower speed limit during winter (four to six months during October–April). The wintertime reduction is from 120 to 100 km/h on motorways and from 100 to 80 km/h on other roads. A policy test was carried out on extending the wintertime limit to the slightly over 200 kilometres of semi-motorways. The present case concerns the reduction of the speed limit on these roads from 100 km/h to 80 km/h for a period of five months. Only link-level impacts are considered.

Presently, the average speed is 97 km/h in the summer and 94 km/h in the winter. It was assumed that a speed limit of 80 km/h would lower the winter-time average speed to 88 km/h. This assumption was subject to sensitivity tests: average speeds of 90 and 85 km/h were used as the minimum and maximum speed changes, respectively.

The average number of personal injury accidents (PIA, including fatal accidents) on these roads is about 30 per winter, resulting in 6 deaths and 46 non-fatal injuries. Thus, the accidents on these roads are often very severe.

#### *Monetary impacts*

Table 3-1 summarises the results regarding monetary impacts. The policy brings benefits to society: the net change of social costs is about MECU –1.9 per winter, which represents 2% of the total costs. The single largest change occurs with accident costs, MECU –2.5 (-27%) per winter, with time losses increasing worth about MECU +1.6 (+6%) per winter. The savings in accident costs were derived from an estimated 13% decrease in the number of injury accidents and a 16% decrease in the average cost on an injury accident.

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<sup>1</sup> Semi-motorways in Finland are rural two or three lane single-carriageway roads with grade-separated junctions and access limited to motor vehicles with structural speed exceeding 40 km/h (thus excluding mopeds and agricultural tractors, for example).



**Table 3-1. Monetary impacts (kECU per winter) of extending the wintertime speed limit to semi-motorways in Finland.**

	Before	After	Change	
Vehicle operating costs	50 828	50 379	-449	-1 %
Time costs	26 831	28 455	1 624	6 %
Accident costs	9 298	6 812	-2 486	-27 %
Air pollution costs	2 795	2 707	-88	-3 %
Noise costs	4 519	4 003	-516	-11 %
<b>Total</b>	<b>94 271</b>	<b>92 355</b>	<b>-1 916</b>	<b>-2 %</b>

The results of the actual policy test (mean speed decreases from 94 to 88 km/h) and the sensitivity tests are summarised in Figure 3-1. The assumption of minimal speed change (MIN, from 94 to 90 km/h) reduces the net change in the social costs to MECU  $-1.3$  per winter. The change in accident costs by MECU  $-1.8$  per winter remains decisive for the net effect, while time costs increase by MECU  $+1.1$  per winter. The upper limit of the anticipated speed change (MAX, from 94 to 85 km/h) alters the net costs with MECU  $-2.5$  per winter. Accident costs decrease by as much as MECU 3.6 or 38% per winter, while time costs increase by MECU  $+2.5$ . In all cases, vehicle-operating costs remain the clearly largest cost item representing over 50% of the total costs. They change relatively little as they include also the fixed costs that are independent of speed.

#### *Distribution of the impacts*

In all cases the group that is most affected by changes in vehicle operating costs (VOC) and travel time costs (TTC) is private motorists, which is natural as cars (and vans) form 88% of the traffic on semi-motorways. However, their share of the changes in these costs is slightly larger, about 92% (see Figure 3-2). The shares of coaches are 3.5% of the VOC savings and 5.8 % of the TTCs as compared to the 1.0% of the traffic, whereas the shares of goods traffic of these cost changes (4.7% and 2.5%, respectively) are clearly smaller than their share of the flow (11%). The coach traffic receives a smaller portion of the VOC savings and pays a larger portion of the TTC increase than lorries. Thus, when one looks at the sum of the changes in vehicle operating and time costs, coaches take a share of almost seven times their share of the traffic whereas the share of goods traffic is only about one seventh of its share of the traffic flow. The explanation to this is that the share of time costs is much higher for coaches than lorries (57% vs. 28% in the initial situation).

The impact functions used do not predict vehicle-type specific accident rates. Thus, it can only be stated that all road users benefit from reduced accidents.

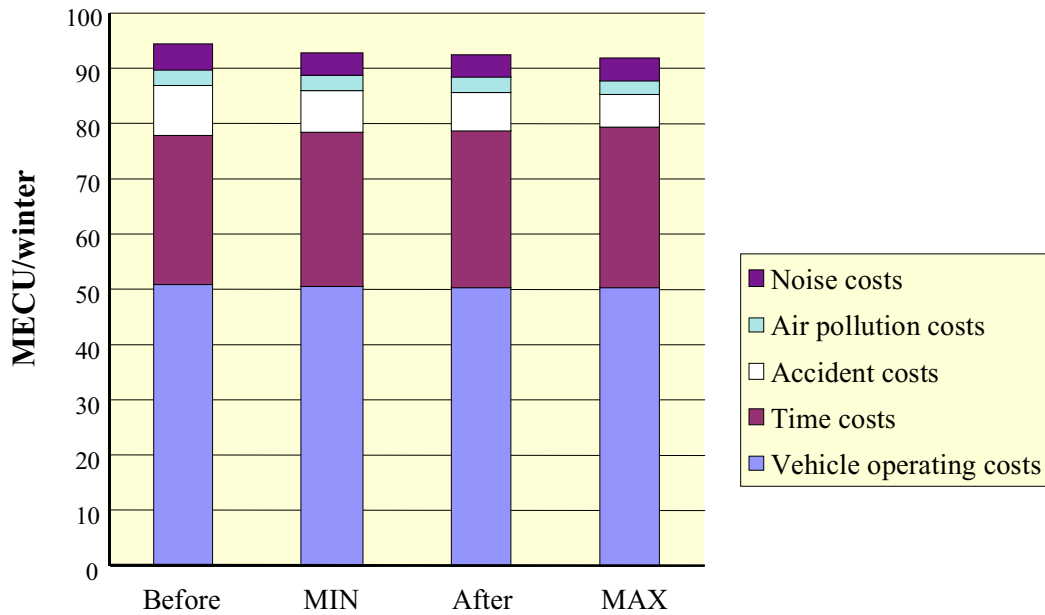


Figure 3-1. Summary of the impacts of introducing a wintertime speed limit on semi-motorways.

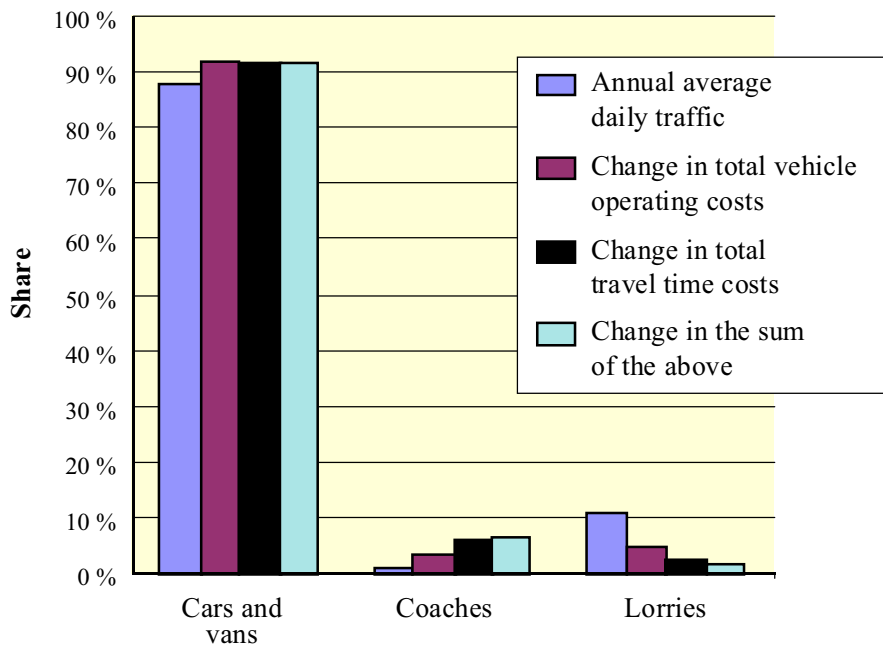


Figure 3-2. Shares of the vehicle types of the traffic as well as of changes in vehicle operating and time costs.

For pollution, it is hard to say which group benefits most. First, it must be noted that the absolute changes of pollutant concentrations are bound to be very small, even insignificant, which renders close to unimportant also the distribution of that change. In principle, however, it can be noted that those living at the roadside are exposed for longer periods than those inside the vehicles, but to lower concentrations than the latter are. The impacts of pollutants having more global effects can be deemed distributed evenly.





The residents of the roadside would benefit most from the somewhat reduced noise levels, because their daily exposure time is much longer than that of any other group. Nevertheless, the noise levels inside the vehicles decrease as well. However, the reduction of the noise emissions and levels is so slight (0.6 dB) that it is hardly significant.

### *Discussion*

Because of the high severity of the accidents, the cost of the average PIA used in the calculations was derived from the observed numbers of deaths and non-fatal injuries and their national unit values, instead of using the national average value on a PIA (kECU 170). Consequently the average cost on a PIA on these roads (kECU 316) was estimated to be almost twice as high as the national average cost of a PIA that is normally used in the calculation of accident costs. Nevertheless, the impact on accident costs probably was still underestimated, because in the lack of better data, the cost of non-fatal injury used in these calculations was the national average (kECU 26), the real cost being most certainly much higher.

Uncertainties are also present in monetising the impacts of pollution and noise. Especially the impacts of global warming are not easily predicted. As carbon dioxide, the most important greenhouse gas, stands for a major part of the air pollution costs, changes in its unit value bring almost corresponding changes to these costs. For instance, if the unit price were tenfold, the total net benefits would be, in the MAX scenario, annually MECU 0.8 higher than in the before-policy situation. The present value is at such a low range that using one tenth of it would not markedly change the overall results.

Overall, the analysis shows that lowering the winter-time speed limit by 20 km/h would bring net benefits to society. The costs of implementing the policy are not considered, but it is not likely that they will come close to offsetting the presented effect. The net effect is fairly small in relative terms (2%). The main conclusion could be that the policy would significantly improve safety at the cost of increases in travel time.

## APPENDIX 4

### Speed advice systems in the simulator experiment

#### (1) Variable message sign



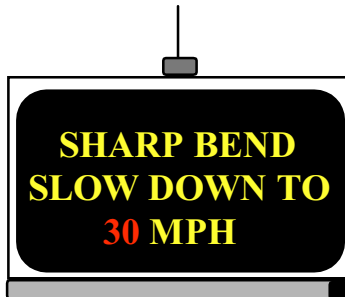
**Dimensions :** 8.6m X 6m

**Positioning :** 100m before curve entry

**Activation:** 300m before curve entry

**Special features :** The sign is activated only when drivers are exceeding the advisory speed. "LEEDS 1" on top refers to register plate. The advisory speed is displayed in red to improve legibility.

#### (2) In-car display



**Dimensions :** 195mm X 150mm

**Positioning:** In the centre of the dash-board, level with the steering wheel.

**Activation :** The message is displayed 250m before curve entry.

**Special features :** The message is activated only when drivers are exceeding the advisory speed. The advisory speed is displayed in red to improve legibility. The message is deactivated at curve entry.

#### (3) Speed limiter interface



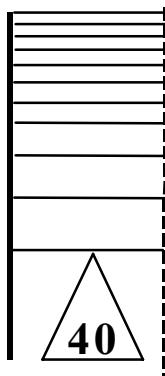
**Dimensions :** 195mm X 150mm

**Positioning :** In the centre of the dash-board, level with the steering wheel.

**Activation :** The message "SPEED CONTROL AHEAD" is displayed 300m before curve entry, and changes to "SPEED CONTROL ACTIVE" 200m before curve entry.

**Special features :** The speed control is deactivated on curve exit.

#### (4) Transverse bars



**Dimensions :** 0.60 metres wide

**Positioning :** At right angles to the centre line of the carriageway. Placed at decreasing intervals from 150m before curve entry to curve apex, as laid out in Department of Transport Standard TD 6/79. Distance between bars ranged from 4.15m -2.75m.

**Activation :** 150m before curve entry

**Special features :** Yellow