# RECOMMENDATIONS FOR SPEED MANAGEMENT ON EUROPEAN ROADS

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## ABSTRACT

Results of a recent European research project MAnaging Speeds of Traffic on European Roads (MASTER) are presented. Speed management is described as a two-step process where target speeds for different kinds of roads are determined first, and then various measures and tools are applied in order to adopt such speed. Current practice and main problems in speed management are described. The various impacts of speed and the factors affecting drivers' choice of speed as well as the various speed management measures and tools are discussed. Basic principles of rational speed management are outlined on these grounds. Finally, recommendations for further development of speed management and research needs are formulated. 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. The recommendations concerning speed management measures and tools include, for example, harmonization of speed limits in different European countries, development of European guidelines for urban speed management, further development and wider use of automated speed enforcement, and introduction of adaptive in-vehicle speed limiters. Further research is needed on the impacts of speed on accidents, pollution and costs to road users as well as on the monetary valuation of these impacts. Standardization of procedures used in collection and reporting of speed data is needed to facilitate international comparisons.

Keywords: Speed, Safety, Management

# INTRODUCTION

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 possible these journey-times 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 European project MAnaging Speeds of Traffic on European Roads (MASTER), funded in part by the European Commission under the Transport Programme of the 4th Framework Programme, was launched with the aim to produce information that can be cited in the preparation of national and EU decisions concerning speed management and standards for speed control equipment. For this purpose, the project seeked 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?

Each of the three research areas addressed one of these questions and consisted of several work packages. Area 1 was concerned with developing a basis for appraisal of effects of different levels of speed upon accident occurrence, emissions, noise, vehicle operating costs and travel time. Area 2 provided information on factors that influence drivers speed behavior with respect to present speed levels and speed management methods in Europe, enforcement levels, motivation and acceptability of driving speeds, and road design and subjective road categorization. Area 3 reviewed various tools for speed management, tested the most promising ones and produced recommendations for implementation of Advanced Transport Telematics (ATT) systems. The results from the three research areas provided the main inputs to the final report, which was concerned with making recommendations for speed management strategies and policies. The full results of the project are documented in the 26 reports listed in the references section of this paper (*1 through 26*). These reports can be viewed and downloaded from the web site http:/www.vtt.fi/yki/yki6.

The present paper describes the main findings of the MASTER project. Chapter 2 outlines the scope of speed management, gives an overview of the present situation and identifies some key problems. The results from the three research areas are described briefly in Chapters 3 to 5, respectively. Chapter 6 contains a description of proposed basic principles for further development of speed management. Based on these principles, recommendations for speed management strategies and policies for different kinds of roads are presented in Chapter 7. Based upon the achievements of the MASTER project the needs for further research are discussed in Chapter 8.

# 2. THE SCOPE OF SPEED MANAGEMENT AND SOME KEY PROBLEMS

## 2.1 Definition of Speed Management

In general speed management can be considered to cover all actions that promote the adoption of driving speeds that are acceptable or desirable from society's point of view. The organization of the project around the three key questions in Chapter 1 is in accordance with this definition. Formulated slightly differently, the objectives of speed management can be seen to consist of two main tasks:

1. Determination of the (target) ranges of speed that would be desirable in different road and traffic conditions.
2. Determination and application of best measures and tools for persuading drivers to adapt such speeds.

This may seem simple and straightforward at first sight, but when the variations in road and traffic conditions, and the number of available measures and tools are taken into account, the task becomes more complicated and demanding. In addition, we recognize that the recommendations should take into consideration pan-European, national and local applications. Furthermore, it is often practical to differentiate between recommendations for short-term and long-term applications.

## 2.2 Current Practice in Speed Management

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 with 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 policemen 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 considerably.

In European 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 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. The recommended speed is lower than the speed limit.

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

Physical measures are used for speed management in increasing volumes in urban areas. Measures such as 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 other. 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 such as pavement treatments or 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 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 administrations, police and traffic safety organizations. The roles of European Community and vehicle manufacturers have been rather minimal in this respect so far. Even though there is co-operation among 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 there can also be big variations in the resources they have available for it.

## 2.3 The Main Problems in Speed Management

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 part of these accidents. Furthermore, the consequences of accidents generally increase with increasing speeds.
2. Table 1 shows that there are great variations in speed limits on similar roads in Europe, even though harmonization of speeds on similar roads would contribute to fluent and safe flow of traffic. Only in urban areas speed limits are broadly in harmony since the general speed limit is 50 km/h with a 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. Motorways 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 a more systematic and comprehensive assessment of all impacts of speed than presently.

4. Speeds frequently exceed the speed limit 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 at 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, it is concluded that speeding is becoming more and more frequent phenomenon all over Europe.
5. Because of the difference between private and social costs of driving at 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 maximization of public welfare, often have to act against the 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 by scientific criteria, 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.

*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 20 European countries (8, 22).*

| | Passenger cars | | | | Trucks | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **BA** | **RR** | **MR** | **MW** | **BA** | **RR** | **MR** | **MW** |
| Austria | 50 | 100 | - | 130 | 50 | 70 | 70 | 80 |
| Denmark | 50 | 80 | 80 | 110 | 50 | 70 | 80 | 70 |
| Finland | 50 | 100/80 | 100 | 80/100/120 | 50 | 80 | 80 | 80 |
| Germany | 50 | 100 | 100 | no limit | 50 | 80 | 80 | 80 |
| Greece | 50 | 90 | 110 | 120 | 50 | 80 | 80 | 80 |
| 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 |
| 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 |
| 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 |

## 3. IMPACTS OF SPEED

The project MASTER arose primarily from concerns about the contribution of speed to the number and severity of accidents causing death and injury. 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. The main impacts of speed are briefly listed below.

**Accidents**

In general, the number and severity of accidents decrease with decreasing speed. A reduction of the mean speed by 1 km/h can be expected to cause a 2 to 3.5 percent reduction in the number of injury accidents, and the relative effect on the number of fatalities and accident costs can be twice as high (*5*).

**Environmental effects**

Of the major pollutants, hydrocarbons (HC) emissions reduce with speed, and oxides of nitrogen (NOx) increase with speed. Carbon monoxide (CO) and particulates have the lowest emission levels at medium speeds. Cold starts and accelerations can increase exhaust emissions disproportionately (*21*). As speed exceeds 40–50km/h noise increases linearly with speed. Acceleration and braking cause a small (1-2dB) increase in noise (*21*).

**Costs to users of vehicles**

User costs that are affected by speed consist mainly of time and vehicle operating costs. In general time costs decrease and other user costs increase with increasing speed. Some of these costs may be quite accurately perceived by the users in terms of time and money; others may be appreciably or even substantially misperceived. Misperceptions affect the users' response to the changes in speed. Furthermore, changes in costs to users do not usually imply equal changes in cost as reckoned by governments from the point of view of society.

**Equity and distributional impacts**

In principle, optimal 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 a method, however, does not take into account the fact that gains from changes in speed for one group of people often mean losses to some other group. From society's point of view, however, such distributional and equity impacts can be equally important as overall efficiency, sometimes even more important.

**Network level impacts**

In the long run speed management can affect traffic volumes on the roads. 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. (*11, 12*)

## 4. FACTORS INFLUENCING DRIVERS' CHOICE OF SPEED

The Theory of Planned Behavior by Ajzen (*27*) is frequently used in traffic psychology. Models built on this theory indicate that driving *behavior* is largely determined by *intentions* which in turn are determined by *attitudes*, *subjective norms*, and *perceived behavioral control*. However, speed behavior is not only driven by motivation, but also by external feedback factors as perceived by the driver, such as road design elements and the behavior of other road users in his surroundings. In Figure 1 a combined overall model is given of the factors that influence drivers' speed behavior.

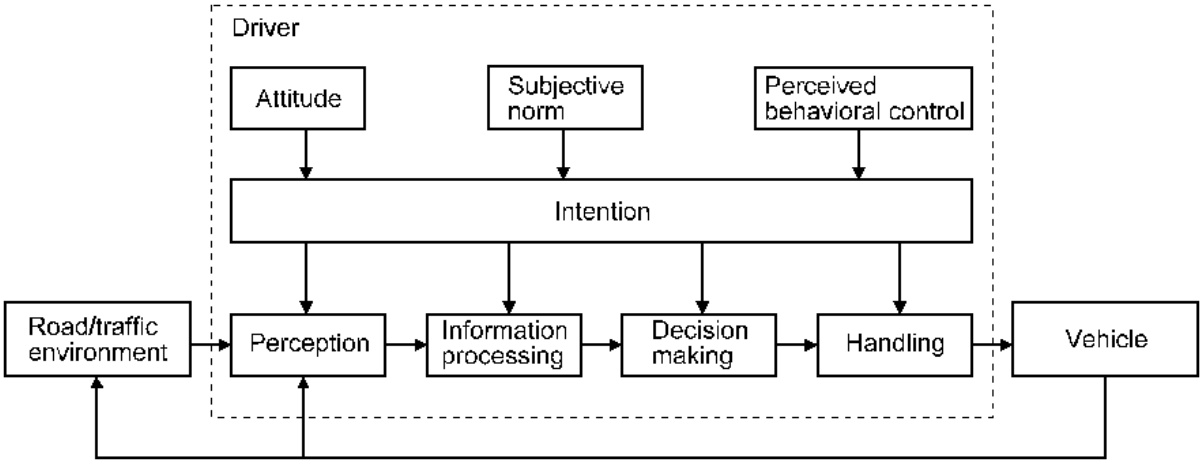


*Figure 1. Combined overall behavioral model to indicate factors that influence drivers' speed behavior (22).*

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 (*20*). In preparation of these interviews, an extensive literature review has been carried out on the relationship between motivation and speed (*16*). Second, relevant aspects of road design elements with respect to driving speed behavior were identified and quantified by experimental driving simulator studies (*6, 14, 15, 17, 18*). Various speed reducing measures were identified and quantified as well. In vehicle speed-limiters were tested in three countries in real traffic conditions on public roads (*23, 24, 25*).

The main factors affecting drivers' choice of speed are discussed briefly in the following.

**Speed and motivation**

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 (*16*).

**Acceptability of present speeds**

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 behavior. 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 (*20*).

**Enforcement**

The impact of enforcement of actual speeds depends on several factors, e.g. a) the actual speed level compared to speed limit, b) intensity of enforcement (risk of getting caught), c) penalty system, and d) publicity. The effects of traditional speed enforcement where policemen measure speeds by radar and stop speeders for ticketing are typically limited in time and space. Automated speed enforcement is more cost-effective and objective (*19*).

**Road design**

Speed reductions can be achieved by isolated physical measures (e.g. speed humps, horizontal deflections and road narrowings, roundabouts, village gateways, pavement treatments and rumble strips) or integrated measures like traffic calming zones in urban areas. Measures that physically restrict driving at high speeds seem most effective, especially speed humps and roundabouts. The effects of many speed reducing measures are localized in time and space. Furthermore, the impact of any particular measure typically depends on the details of its design (*9, 17, 18, 22*)

Physical measures typically force road users to reduce speed, instead of persuading them to reduce speed voluntarily. A more optimal 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

choose the appropriate driving speed more or less automatically. At the moment, road categories as perceived by drivers do not seem to correspond with the official road categories. (*17, 18, 22*)

**Telematic measures**

Advanced Transport Telematics (ATT) offer opportunities for providing feedback to individual drivers, of implementing variable speed limits to maintain traffic flow and of automating longitudinal control by means of speed limiters and adaptive cruise control. In general, intervening systems are more effective in reducing speeds. Informative systems, on the other hand, appear to be more acceptable to drivers.
In field tests conducted in three countries using an instrumented vehicle, with all the instruments hidden and the subjects driving alone, the speed limiter reduced speeds significantly on roads with speed limits from 30 to 70 km/h. The effect of the speed limiter was greatest in free driving conditions, when there was little other traffic affecting driver's choice of speed (*23, 24, 25*).

## 5. SPEED MANAGEMENT TOOLS

A variety of measures and tools is currently used for speed management, and other efficient and technically feasible solutions such as adaptive in-vehicle speed limiters are potentially available, but their introduction has been delayed mainly because they do not always have wide public support. Most important current and potential future speed management measures and tools are listed below.

**Informative and Legal Measures:**

- Posted speed limits
- Variable speed limits
- Vehicle and driver type specific speed limits
- Penalty systems for speeding
- Speed recommendation signs
- In-vehicle information of prevailing speed limit
- Feedback on speed (road-side or in-vehicle)
- Education and publicity campaigns

**Measures Related to Road Design:**

- Speed humps
- Road narrowings and horizontal deflections
- Roundabouts
- Village gateways
- Pavement markings
- Rumble strips and other pavement treatments
- Visibility and visual guidance
- Traffic calming
- Self-explaining roads

**Intervening measures:**

- Conventional speed enforcement
- Automated speed enforcement
- Adaptive cruise control
- In-vehicle speed limiters

These have been assessed in terms of their impacts of speed, other relevant impacts and cost-efficiency (*13*). These assessments served the generation of recommendations for further development of speed management presented in Chapter 0.

## 6. BASIC PRINCIPLES OF SPEED MANAGEMENT

The recommendations presented in Chapter 7 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) (*28*). 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 that 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 one hand and the need of pan-European harmonization on the other hand.
4. Speed management, both the target ranges of speed and the 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 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 significant weight on public opinions or acceptability in decision making regarding speed management.
5. The decisions concerning speed management should be based on to 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 of population.
7. Driving speeds should be in harmony with the road environment so that the environment advances 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 instances responsible for speed management should have compatible ideas of the general objectives of speed management, target speeds and measures and tools for adoption of such speeds.
11. It follows from points 9 and 10 above that speed management should have a long term plan to guide the implementation and development of measures and tools.

# 7. RECOMMENDATIONS FOR SPEED MANAGEMENT ON DIFFERENT KINDS OF ROADS

The recommendations presented below follow the two-step structure described in section 2.1. Consequently, recommendations concerning the determination of target speed are presented first, followed by recommendations for application of measures and tools for adopting such speeds.

## 7.1 Recommendations for Determination of Target speeds

Determination of target levels of speed on different kinds of roads should be based on comprehensive and systematic assessment of all impacts of speed. The MASTER framework was developed with this kind of application in mind. The framework is based on a schematic model presented in Figure 2, and the steps of its application are described in Figure 3.

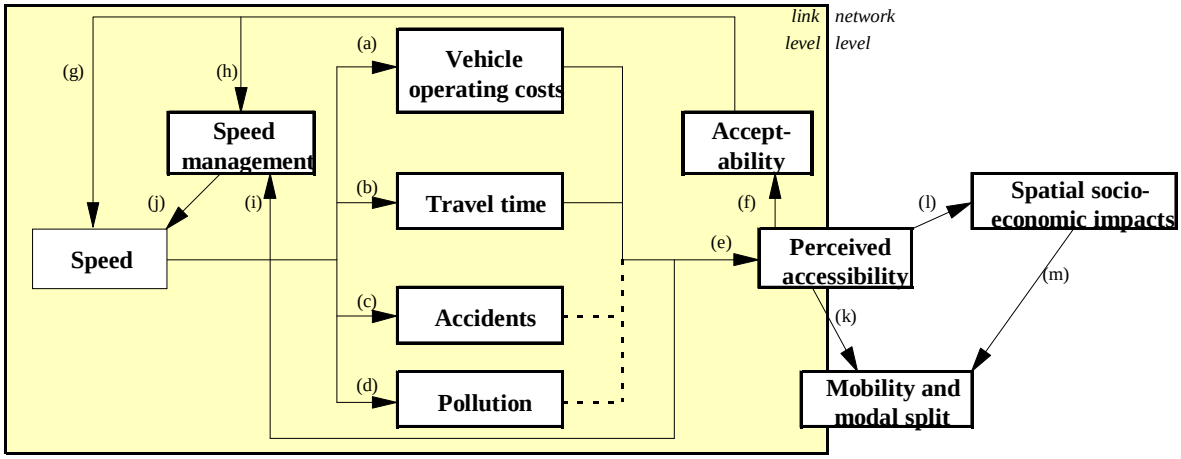


*Figure 2. A schematic description of the impacts of speed by Kallberg and Toivanen (12).*

| 1. Outlining | ⇒ | 2. Measurement or estimation | ⇒ | 3. Assessment |
|---|---|---|---|---|
| A. Deciding the measure or policy to be tested | | D. Choosing the impact functions or models and gathering data | | H. Summarising the net impacts |
| B. Deciding on link or network level assessment | | E. Deciding on which impacts to monetise at what monetary value | | I. Analysing the distributional effects |
| C. Establishing which impacts are relevant to the case concerned | | F. Making the calculations | | J. Making sensitivity tests with the key assumptions |
| | | G. Analysing the extent of non-quantifiable impacts | | K. Analysing the acceptability of the policy |
| | | | | L. Analysing the overall socio-economic feasibility of the policy |

*Figure 3. Structure of the MASTER framework.*

The impact functions that describe the effects of speed on various factors (e.g. on vehicle operation costs, accidents, exhaust emissions and noise) are chosen by the user. So are the monetary values of different effects where these effects can be expressed in such terms. The point of departure was the inclusion of a social cost-benefit analysis including the assessment of both the magnitude and distribution of impacts. It is recognized that not all impacts can be expressed in financial terms. The framework can be applied for either network or link level assessment. The former takes into account the indirect effects of speed on traffic volumes and can be laborious. The latter assumes that speed does not affect traffic volumes and is more straightforward.

The output from the application of the framework normally includes all essential knowledge, not only the results, but also the data and assessment methods used. The whole assessment process in the MASTER framework is transparent and open to criticism.

The output is in the same order as the assessment process and should include 1) outlining of the case and basic data, 2) list of impacts included in the assessment, 3) description of impact functions and calculations, 4) presentation of quantitative impacts, and their monetary values where applicable, and qualitative impacts, 5) distributional impacts, and 6) sensitivity tests.

It is recognized that often quantitative effects on different scales, and qualitative effects cannot be aggregated without considering their relative weights. This is left to the decision-makers.

The use of the framework with the help of a specially designed Excel spreadsheet in three real cases from Finland, Hungary and Portugal is illustrated by Kallberg and Toivanen (*12*).

Decision makers on various levels have an important role in speed management. They should be informed of the difference between private and social costs, its impact on public acceptability of different speed management strategies and tools, and the fact that popularity is not necessarily a good criterion for sustainable speed management.

### 7.2 Recommendations for Speed Management Measures and Tools

Recommendation of general nature are listed below.

1. Speed limits on similar roads in different European countries should be harmonized 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 desired speeds determined according to the guidelines described in the previous section.
2. European guidelines are needed for application of speed management measures and tools in urban areas, for both residential and main roads. This would promote efficient and consistent speed management, especially on urban roads, where a wider range of potential alternatives is available than on rural roads where the possibilities for using low-cost physical measures are more limited.
3. Preparations for introduction of compulsory adaptive speed limiters should be started. Adaptive speed limiters automatically prevent speeding and adjust speeds according to the prevailing speed limit. The first step could be large scale field experiments in urban areas in different countries. Urban roads are the best choice for the first application area because there their public acceptability is highest and potential negative effects e.g. in the form of behavioral adaptation are smallest.
4. Hierarchical categorization and (re)design of European roads into a limited number of categories so that each road category has a distinct set of characteristics that is clearly different from that of other categories. A reduced and simplified road hierarchy would promote correct choice of speed and also have other positive effects on road safety by promoting correct anticipation.
5. Automated speed enforcement should be developed further and taken into wider use. In some countries legislative changes are needed so that the owner of the vehicle can be held responsible for speeding offences. In addition, a common standard could be developed for identification of vehicles by an electronic device. Currently speeding vehicles are identified from photo which often requires manual work and is laborious. Electronic identification devices could be used also for collection of parking fees and road tolls, for example. Furthermore, equipment that is presently used only for traffic monitoring could be used for enforcement purposes (e.g. induction loops and data transfer equipment).
6. The difference in the effects of speed between social and private costs should be reduced, for example by internalizing external costs (e.g. accident costs and environmental costs). This would persuade drivers to choose speeds that are more optimal not only from their private standpoint but also from society's point of view.
7. Information and publicity campaigns regarding the impacts of speed are needed, with the purpose of giving neutral and objective information on all impacts of speed, with due attention on the difference between private and social costs. Such information could increase the public approval of speed restrictions that are justified from society's viewpoint.
8. The highest possible speed of vehicles should be limited to the highest possible speed limit on motorways and speed limits on motorways should be harmonized across Europe.

In addition, more detailed recommendations regarding speed management on different kinds of roads (urban residential roads, urban main roads, rural two-lane roads and motorways) are presented by Kallberg et al. *(13)*.

## 8. Recommendations for further research

During the project MASTER several subjects came up where additional research could serve the further development of speed management in road transport. The main areas for such research are listed below.

1. Further research and modeling of the impacts of speed on different exhaust emissions, noise, vehicle operating costs and time costs so that the speed dependencies of different factors would be easy to use in determination of target speed.
2. Present knowledge of network effects of speed is insufficient, e.g. there is little knowledge of the elasticity between speed and traffic volumes.
3. More information is needed of the use of different kinds of roads in the course of different kinds of journeys for improved prediction of the impacts of different speed management policies.

4. Research of the impacts of changes in speeds on accidents 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 bases of previous studies on the impacts of lowered speed limits on accidents, for example.
5. There are large variations among 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 harmonization of speeds.
6. There are no commonly accepted procedures for due consideration of distributional and equity impacts of changes in speed. Research is needed to fill this gap.
7. The present practice of monitoring the speeds on different kinds of roads is different in different countries. Standardization of collection and reporting of speed data would help in the identification of problem areas in speed management.

## 9. ACKNOWLEDGMENTS

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