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Best Practice for Cost-Effective Road Safety Infrastructure Investments



Full Report

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EXECUTIVE SUMMARY

The EU target of reducing fatalities by 50% (European Commission, 2001) within a decade will only be achieved through the introduction of the most effective road safety measures, therefore, their economic appraisal is considered a very important tool in the hands of decision makers. Within the O7 Task Group of CEDR, an effort to understand, identify and disseminate best practice to ensure cost - effectiveness on road safety investments has been initiated, as part of a broader Strategic Plan which defines the priorities that the organisation has set for the four years period 2005 - 2009 and aims to **assist and guide for more efficient National Road Authorities**. The current Report will also supplement the previous CEDR report titled "Most Effective Short-, Medium- and Long-Term Measures to Improve Safety on European Roads" (CEDR, 2006), by quantifying and subsequently classifying several infrastructure related road safety measures.

The objective of this Synthesis is the **identification of best practice on cost-effective infrastructure related road safety investments**, based on the international experience attained through extensive and selected literature review and additionally on information/data collected through a questionnaire based survey, launched by the Task O7 Group. For the achievement of the above objectives an appropriate methodology was adopted: Initially, a review of selected reference documents dealing with cost-effectiveness studies of implemented road safety investments both in EU and worldwide takes place and the road safety strategies in the European countries are examined on the basis of the Questionnaire 1 of the CEDR O7 Group. At a second stage, several infrastructure related road safety investments identified through the literature review, but also through the analysis of the Questionnaire 2 of the CEDR O7 Group and the previous CEDR report, are further investigated and a preliminary ranking is attempted.

In this Synthesis, a complete list of **55 examined road safety investments** is presented in an exhaustive literature review. These are classified according to the type of infrastructure they can be implemented (general, motorways, rural roads, junctions, urban areas). Out of these 55 investments, more than half can be applied on simple road sections, even more of them on bend sections and others can be applied on junctions. Additionally, more than half of the investments can be applied in more than one infrastructure element.

Both the implementation costs and the safety effect of each investment are ranked as "high" or "low", according to the results of the review. It is noted that this concerns an overall ranking, as the cost and safety effects of an investment may also depend on the scale of implementation (e.g. local or area-wide) or on the type of implementation (e.g. simple or more complex implementation). In general, **an investment combining a high safety effect with a low implementation cost is considered to be the most preferred**.

Although no general rule can be formulated for a particular infrastructure category or investment area, individual investments that fulfil the optimal requirements can be found in all infrastructure categories and in most investment areas within this category. Within this Synthesis, it was proved that there is an important number of cost-effective road safety investments, having low cost / high safety effect or high cost / high safety effect, which may be implemented for addressing various road safety problems. This overall assessment allowed for the **selection of the following five investments**:

- **Roadside treatments** (clear zones, safety barriers)
- **Speed limits**
- **Junctions layout** (roundabout, realignment, staggering, channelisation)
- **Traffic control at junctions** (traffic signs, traffic signals)
- **Traffic calming schemes**

For each investment, an **in-depth assessment** is carried out, including detailed descriptions, statistically validated safety effects, other effects (mobility, environmental etc.) and implementation costs, which revealed the range of safety effects, implementation costs and eventual cost-effectiveness that can be expected when implementing these five road safety infrastructure investments. It should be underlined though that the above ranges of results can be considered to apply in every application of these investments. Moreover, strengths, weaknesses and barriers to implementation are investigated in each case. Based on the outcome of the above mentioned analysis, a synthesis of Best Practice for Cost - Effective Road Safety Infrastructure Investments is elaborated, and furthermore, the basic issues that need to be taken into account for an optimal implementation of efficiency assessment in decision making are outlined.

The above best practice examples would be optimally used as **an overall guide towards a more efficient planning of the investments**. However, given that no "magic recipes" or panaceas exist when it comes to the final assessment and decision, thorough analysis on a case-specific basis is always required, in order to optimise the implementation of the investment in different countries or areas, according to the extent of the implementation, the implementation period and the specific national or local requirements. Furthermore, it is necessary to ensure that analyses are carried out according to standard and acknowledged methodologies.

Additionally, given that no generalised rules can be formulated for decision making, some fundamental principles on the successful application of efficiency evaluation techniques on infrastructure related investments are noted, exploiting the experience attained through the extensive relevant literature review of several case-studies worldwide. Consequently, this Synthesis can be considered as a **complete proposal for best practice on road safety investments**, which could be used as a reference by any Road Authority for the selection of the most appropriate road safety interventions.

1 INTRODUCTION

1.1 Scope and objective

Economic appraisal of road safety measures is considered a very important tool in the hands of decision makers. Within the O7 Task Group, an ad-hoc group of the broader "Road Safety" Group of the **Conference of European Directors of Roads (CEDR)**, an effort has been initiated to understand, identify and disseminate best practice to ensure cost - effectiveness on road safety investments. This initiative is part of a broader Strategic Plan which defines the priorities that the organisation has set for the four years period 2005 - 2009; this plan aims to assist and guide national road authorities in their efforts to become more efficient, ensuring an improved contribution by road transport to the wider economy, safer transport, and a more harmonious relationship between road transport, transport users, society and the environment.

Within the framework of task group O7 activities, two questionnaire-based surveys were carried out, with the aim of identifying road safety practices and cost-effective, infrastructure-related investments in various European countries. This exercise had to address a number of complex issues, some of which still exist, such as:

- difficulties in isolating the safety effect of a specific investment, as in many cases the estimation of a safety effect can be attributed to the implementation of more than one road safety measure,
- difficulties in aggregating the information/data collected due to the high diversification of road safety investments,
- difficulties in comparing information/data among countries due to:
 - differences in the road environment and their related road elements,
 - differences in methodologies for the calculation of safety effects,
 - differences in actual investment costs among countries.

These issues require careful examination, to allow for the development of a clear overall picture of cost-effectiveness in infrastructure-related road safety investments at EU level.

The primary objective of this synthesis is to provide road directors with a best practice guide to assist them in their initial strategic choice of infrastructure-related investments that aim to improve road safety, by means of:

- gathering available information in an exhaustive literature review,
- organising and comparing existing experience based on the effectiveness of investments,
- identifying and analysing the most promising sets of investments,
- suggesting the conditions for optimum implementation of the selected investments.

The final output of this synthesis is a **guide to best practice for cost-effective road safety infrastructure investments**.

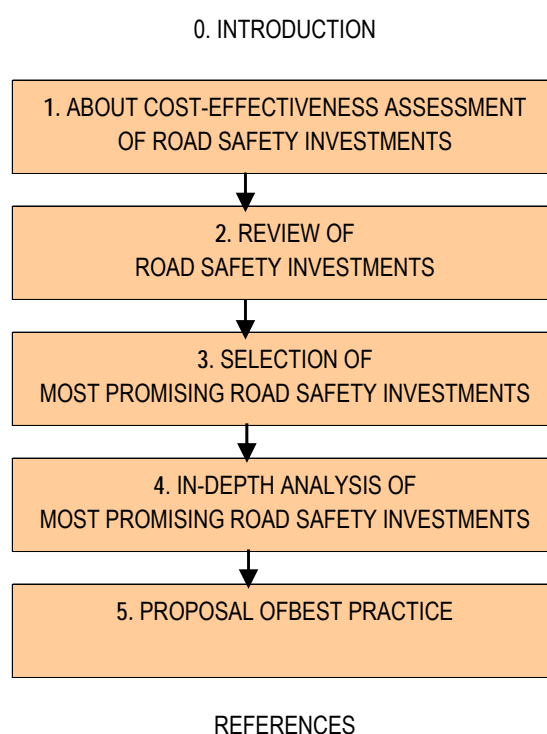
This best practice guide is based on an analysis of a considerable amount of information/data. The majority of this information/data was collated from the results of two questionnaires (questionnaire 1 and questionnaire 2 issued by task group O7), and from information attained through an exhaustive review of the literature on the efficiency of road safety measures already implemented in European countries and worldwide. In addition, this synthesis will complement an earlier CEDR report, Most Effective Short-, Medium- and Long-Term Measures to Improve Safety on European Roads, by quantifying and subsequently classifying several infrastructure-related road safety measures.

It should be noted, however, that this best practice guide does not in any way replace the subsequent specific studies that are necessary for the selection, design, and implementation of the measures that are appropriate for each specific case.

1.2 Methodology

To achieve the above objectives a five step methodology was adopted, as presented in the following Figure 1.

Figure 1.1 Methodology Flow Chart



1. Review of selected reference documents

This task concerns a bibliographical review of the current methodologies and practices dealing with cost-effectiveness studies of road safety investments both in EU and worldwide. The main objective consists of getting a good knowledge of the current cost-effectiveness state-of-the-art of road related safety measures, in terms of data/methodology availability and use. A currently existing list of reference documents including appropriate reports prepared by the Conference of European Directors of Roads (CEDR, 2006), reports of relevant EU financed projects like ROSEBUD and PROMISING, reports on the implementation assessment of selected road safety investments at local and national level from various EU countries, as well as key publications in the field (i.e. Rune Elvik's "The Handbook of Road Safety Measures", PIARC's road safety manual, Highway Safety Manual, etc.) was used for the review. Moreover, the answers of the various countries to the Questionnaire 1 disseminated by the Task O7 Group were considered at a first stage. Special emphasis was given to road safety investments, implemented on roads with specific characteristics, such as motorways and primary roads of the national road networks, as well as on roads with heavy traffic volumes.

2. Investigation of selected road related safety investments

Based on the results of the review of the reference documents and the analysis of Questionnaire 1, selected road related safety investments were further investigated. More specifically, experience attained from the literature review, as well as the feedback to the relevant questions provided from several countries, was exploited and used as a starting point for the update of the list of road related safety investments included in Questionnaire 2 of the O7 Group. Some of these road safety investments were merged or removed and additional ones were also considered when necessary.

3. Cost-effectiveness assessment of road safety investments

On the basis of the above mentioned updated list, the selected road related safety investments were analysed using the input from both Questionnaire 1 and Questionnaire 2 answers, the reference documents and any other contribution from the O7 experts. Assessment of these investments was based on the identification and further examination of the key elements determining the level of the various interventions' efficiency. The safety effect of the various countermeasures was estimated using both methodologies, before and after studies and statistics comparisons and was validated according to the results of the literature review. Appropriate cost-effectiveness ratios were calculated, taking into account the safety effect and the implementation costs of the investments, but also the conditions under which the various road safety investments are implemented were considered.

Following the above mentioned assessment, the selected road related safety investments were ranked in terms of cost-effectiveness and the most cost - effective of them (presumably not more than 5) were selected.

4. Best practice on cost-effective road safety investments

The road infrastructure related safety investments selected in the previous task were further analysed in order to identify their strengths, weaknesses, as well as the barriers to their application and the results of their implementation on the road safety level and on the road user's behaviour, in different cases. Additionally, differences between the examined road safety investments were considered, comparisons on the implementation of similar road safety measures among different countries took place and thus, a complete proposal for best practice road safety investments was formulated. The final output of this Synthesis can be used as a reference by any road authority wishing to justify the selection of the most appropriate road related interventions.

1.3 Structure of the Synthesis

The present Final Report includes an extensive literature review of selected reference documents, exploiting existing knowledge and experiences on the implementation of cost-effective road safety investments. Through this task, the effects of selected road related safety investments were investigated and assessed in relation with their implementation cost. The experience of CEDR member countries is also exploited through the analysis and synthesis of the responses in the two Questionnaires mentioned above and a preliminary ranking of the various identified road safety investments is proposed.

More specifically, **Chapter 2** of the present Synthesis concerns an overall discussion of cost-effectiveness assessment for road safety investments, presenting initially existing road safety strategies, implemented in various European countries. The need for identifying best practice on road safety investments is further described and the theoretical background of the most important efficiency-assessment methodologies is provided. The cost-effectiveness and cost-benefit ratios are defined and appropriate methodologies to calculate the safety effects of road safety investments, as well as the relevant costs (accident and investment implementation costs) are presented.

Chapter 3 of the present Synthesis concerns a complete review of road safety investments, which are related to the road infrastructure. The investments identified in the literature review, but also in Questionnaire 2 of the Task Group O7, can be broken down into five main categories of interventions: general, motorways, rural areas, junctions and urban areas. The main characteristics, overall safety effects, other effects, costs and cost-effectiveness results are presented for an exhaustive list of 55 individual infrastructure investments.

Chapter 4 of the present Synthesis concerns a summary and development of the review presented in Chapter 3. The various investments are classified and assessed in detail according to their type, their characteristics, their safety effects, their costs and their acceptability. This ranking allows for the identification of the most promising investments in terms of cost-effectiveness. Finally, five investments are selected as most promising for further analysis, namely roadside treatments, speed limits, junctions layout, traffic control at junctions and traffic calming.

Chapter 5 of the present Synthesis concerns an in-depth analysis of the five selected investments. The results of the literature review are exploited and further investigated. In particular, for each investment, an in-depth assessment is carried out, including detailed descriptions, statistically validated safety effects, other effects and indicative implementation costs. The cost-benefit ratio of each investment is finally estimated by means of the available studies and the conditions leading to maximum cost-effectiveness are identified. Moreover, strengths, weaknesses and implementation barriers are investigated in each case.

Finally, **Chapter 6** concerns a synthesis of Best Practice for Cost - Effective Road Safety Investments, on the basis of the analyses and findings of the present Final Report. The five most promising investments are assessed comparatively, also in light of their possible inter-relations. Guidelines and recommendations are proposed, both for the optimal exploitation of the results of the present Synthesis, and for the optimal implementation of the most promising investments. Moreover, the basic issues that need to be taken into account for a correct implementation of efficiency assessment in decision making are outlined.

1.4 NTUA research team

This Synthesis on cost-effective road safety investments is developed by the road safety research team of the Department of Transportation Planning and Engineering of the School of Civil Engineering of the **National Technical University of Athens**, under the scientific coordination of George Yannis, Assistant Professor. The research team mainly consists of:

- George Yannis (Scientific Responsible)
- Petros Evgenikos, Civil Engineer - Researcher
- Eleonora Papadimitriou, Civil Engineer - Researcher

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2 COST EFFECTIVENESS ASSESSMENT OF ROAD SAFETY INVESTMENTS

Despite the important decrease in the number of road accident fatalities in Europe during the last decade, there are certainly many more actions to be taken in order for a further decrease of road accident victims in Europe to be achieved. In 2005 more than 41.000 people were killed and approximately 1.7 million people were injured on the roads of the 25 Member States of the European Union (Yannis et al., 2006) and the estimated cost of these casualties to the society is approximately 160 billion euros (European Commission, 2003). Road safety is considered as a high priority issue in all European countries and also at EC level. In 2001 the European Commission adopted a target of reducing fatalities by 50% (European Commission, 2001) within a decade and identified several areas where it could make a direct contribution within the constraints of resources. This EU target will only be achieved by the introduction of the most effective countermeasures, therefore, it is essential to know the reduction potentials of the various road safety initiatives.

In 2006, the Conference of European Directors of Roads developed a report on the most effective road safety measures to improve safety on European roads (CEDR, 2006), following an agreement with the European Commission. Special emphasis was given to the European target of reducing road fatalities by 50% by 2010 and on the occasion of this report, it was also attempted to identify the scope of responsibilities of Road Directors, by looking at institutional and organisational issues in the Member States.

Halving the number of deaths on European roads by 2010 constitutes a serious collective undertaking of all organisations and institutions involved – governmental and non-governmental, responsibilities for road safety are shared between different groups, thus interaction at all levels of government, whether local, regional, national or EU, as well as the private sector, is needed to ensure that the targets are met. Under this perspective, 20 categories of road safety initiatives were considered by representatives from 18 EU-Member States, according to their implementation time span, but also to the level of implementation (national or EU level). The analysis covered a broad range of infrastructure, driver and vehicle related measures.

The study showed the high importance of influencing human behaviour by means of awareness campaigns at national and at EU levels, whose effects can be greatly intensified by legislative measures and appropriate enforcement. Measures related to infrastructure management, such as Hazardous Locations (Black spots) Management, Road Safety Audit, and Road Safety Inspection, are generally recognised as a high priority, especially at national level. High priority is also dedicated to other infrastructure treatments, such as speed enforcement, traffic calming and speed management, at both national and European level.

Following this work, the present Synthesis focuses on infrastructure related investments. An in-depth analysis is carried out in order to create a concrete and overall picture on the characteristics, safety effects and implementation costs of each infrastructure related investment. From this process, an efficiency assessment of the infrastructure related investments will be carried out.

In this Chapter, existing national road safety strategies, implemented in various European countries are further described. These strategies do not always aim at identifying the most effective investments. In particular, in several cases, only overall national goals or strategies are defined, which lack specific quantitative targets and do not consider efficiency assessment results. Therefore, the need for identification of best practice on the selection and implementation of road safety investments by means of efficiency assessment techniques is also highlighted in this Chapter. Furthermore, the theoretical background of the most important efficiency-assessment methodologies is provided.

2.1 Road safety strategies in the European countries

To achieve the objectives of this Synthesis, data collected by a questionnaire-based survey, focusing on general information regarding national efforts on road safety were initially used. Road safety experts from most European countries representing different areas of the European Union filled in the questionnaire. These responses provided an overall view of the current situation regarding road safety policy issues. This survey took place within the framework of the activities of the **task group O7 of the road safety group** of the Conference of European Directors of Roads (CEDR).

Experts from 16 European countries completed the questionnaire: Austria, Belgium (Wallonia), Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Slovenia, Switzerland, and the United Kingdom.

The following section analyses the results and proposes a synthesis of the answers to the questionnaire in order to define the current situation in Europe regarding national strategies for road safety. Answers to each question are summarised and then examined in terms of consistency and comparability to allow a further comparison of different European areas.

Setting national goals on road safety is common practice among European countries. Even though France does not have a road safety plan with pre-defined targets (in terms of a specific reduction in fatalities to be reached within a certain time period), an annually updated action plan on road safety is adopted. Other European countries set specific targets.

- Many countries (Austria, Germany, Greece, Portugal, Slovenia) have adopted the common EU target set by the European Commission in 2001 (European Commission, 2001), namely to reduce the number of fatalities by 50 per cent by 2010 (based on different reference years ranging from 1998 to 2003).

- Other countries have targets for the reduction of the number of road accident fatalities and injuries ranging from 10 per cent (for slight injuries, in the UK) to 50 per cent (for fatalities, in several countries) within a specified period of time. For example, in the Netherlands targets of a 45-per cent reduction in fatalities and a 34-per cent reduction in hospital-treated injuries by 2020 have been set.

Consequently, European countries adopt individual **traffic safety action plans** that are appropriate for the achievement of specific targets set at national level:

- With the exception of France, where only actions concerning the national road network are carried out, all other countries have implemented specific road safety action plans at national level in order to achieve their predefined goals. In most countries, the national traffic safety action plans provide a general framework, within which various road safety actions are grouped in broader categories.
- In some countries, several different traffic safety plans may be developed, depending on the intended level of implementation. In the Netherlands, for example, there are traffic safety action plans at three distinct levels. At European level, consideration is given mainly to vehicle technology-related measures (active and passive safety). At national level, initiatives related to road pricing, selection of cost-effective infrastructure measures, maintenance of national roads, training of novice drivers, safety campaigns, and vehicle controls are included. Finally, at regional level, special regional traffic safety plans based on the same targets as the national plans are developed and mainly concern the selection of cost-effective infrastructure measures, programmes for improving behaviour of drivers, speed limit enforcement, helmet and safety belt usage, aggression and alcohol, and safe freight transport.

Generally, several **different areas of action** are included for consideration, the most common of which in several countries are:

- the effect of the human factor on road safety levels (human behaviour, education, road safety campaigns, vulnerable road users),
- the infrastructure (the road network, junctions, hazardous location (black spot) management, other engineering-related issues),
- transport policy (co-ordination of authorities, implementation of road safety-related laws, intensification of enforcement, actions related to speed, and alcohol and/or drugs),
- vehicle technology and safety (active and passive safety, accidents involving heavy goods vehicles or two-wheelers, etc.).

In Italy, for example, the national road safety plan for 2003 established three sets of potential types of intervention:

- urgent road safety improvements (funding of road safety improvements in rural and urban high-risk locations),
- systematic interventions (implementation of maintenance and management plans, including information campaigns, traffic planning, multi-modal planning),
- strategic plans (development of regional road safety monitoring centres in 17 of the 21 Italian regions, for monitoring road safety levels).

It is clear that road safety actions differ among European countries in relation to each country's current road safety level, special needs, the specific characteristics of their road traffic and safety culture, and geographical position.

With the exception of Luxembourg, **special traffic safety schemes** have been adopted in all European countries that responded to the questionnaire. More specifically, all of these countries have adopted traffic safety schemes aimed at the identification and management of hazardous locations. A uniform statistical method of identifying hazardous locations throughout the national road network of each country is usually implemented. In Italy, however, hazardous locations are identified on the basis of best practice analysis developed by each regional roads department. In some countries (e.g. Germany), two methods are used to identify dangerous road sections, namely traditional black spot management and network safety management, which concentrate not only on specific hazardous locations but also on the entire road network. In Slovenia, hazardous location management is carried out only for certain road types, more specifically for all roads except motorways. Hazardous location management includes the identification (as defined by each country) and implementation of appropriate measures to mitigate the number of road accidents. The implementation of such measures is normally prioritised, with prioritisation based on certain criteria, usually related to the effectiveness of each measure, but also to its implementation cost (e.g. in the Netherlands in terms of reducing the number of fatalities/injuries).

In almost all countries (with the exception of Luxembourg), **special funding** is allocated to the improvement of road safety levels. Ministries that are responsible for road transport, ministries of justice, and general road directorates are usually responsible for the allocation of these funds, but in some cases regional authorities may also provide financial support for regional projects (i.e. Austria, France). Funds are allocated to various activities in accordance with the specific road safety targets identified and set in the road safety plans of each country; their allocation also depends on the prioritisation of road safety activities within each country. Relevant investments mostly concern the improvement of road infrastructure by implementing short-term interventions and hazardous location management.

Specific budgets for road safety research are less common, but are available in some countries (e.g. in Austria and Switzerland). In general, overall **road safety budgets** are allocated in relation to the national annual budget, GDP, and the size of the countries. For example:

- In Greece, according to 2005 data, a total of approximately €93 million is allocated to road safety actions, with large amounts allocated to mainly short-term interventions at hazardous locations, short-term interventions on the national road network, and enforcement of better driving behaviour by means of electronic cameras.
- In Iceland, according to the national road safety plan, approximately €19.3 million will be spent directly on road safety in the period 2005 - 2008, excluding the costs of major changes in infrastructure, whereas in Ireland in 2006, €33 million was allocated to road safety initiatives.
- In France, approximately €66 million was allocated by governmental and local authorities to the development and improvement of a 30,000-km long road network in 2005.

In the majority of countries, the competent authorities such as national budget administrations, transport administrations, and local authorities determine the amount of funding allocated to road safety.

The choice between various road safety initiatives is usually based on **economic evaluation** (calculations based on economic indicators such as IRR, NPV, first year rate of return, etc.) and less frequently on other criteria. The United Kingdom uses a specific procedure that involves a scoring method for the safety and economic assessment of road schemes. The philosophy behind this scoring system is that the main indicator of value for money will be the first year rate of return for the initiative under assessment. All European countries surveyed, with the exception of Slovenia, where no systematic economic appraisal of road safety initiatives is undertaken, assess the benefits of road safety initiatives and define specific priorities by comparing the cost of the project to be implemented with its potential benefits. The cost of a road safety initiative is equal to its construction/implementation costs, while its benefits are expressed in terms of cost reduction through the potential decrease of road accidents that would result.

Although **cost-effectiveness studies** are widely adopted in order to prioritise road safety initiatives, other factors are also considered. In Switzerland, for example, the feasibility of implementing each measure, the protection of vulnerable users, the impact of each measure on personal freedom, and its compatibility with goals in other fields of federal policy are all taken into account. In France, a general socio-economic assessment is carried out, taking into consideration not only road accident costs, but also the costs of other effects such as time benefit and environmental issues.

2.2 The need for best practice of road safety investments

1. As discussed above, most countries develop and adopt road safety programmes incorporating both a range of road safety measures and a set of targets (e.g. percentage reduction of fatalities within a certain period). **Infrastructure-related road safety initiatives** constitute a large proportion of the overall road safety measures implemented in these countries. These initiatives may include the development of new infrastructure elements or the rehabilitation and improvement of existing elements.

However, as infrastructure-related road safety initiatives usually have high implementation costs and as budgets for road safety policies worldwide are not infinite, politicians have to make decisions regarding the best possible use of these budgets. The criteria used in most countries when deciding on policies and budgets are mainly **suitability, lawfulness, and/or legitimacy**. However, in recent years, **efficiency** has also been frequently cited as a primary criterion for a good policy, and its assessment may contribute to greater rationality in the selection and application of road safety measures, preventing these from becoming merely routine decisions.

2. As a source of information and a means of supporting political decision-makers in their choice of appropriate measures for the improvement of road safety levels in their countries, analytical instruments that measure the efficiency of such measures are required. The initial selection and ranking of projects are facilitated by the application of **cost-benefit and cost-effectiveness analyses** (CBA and CEA), which examine the profitability as well as the relative expedience of these investments. The allocation of budgets for road safety measures can begin with the application of single measures, which are then combined as a package, in a way that achieves maximum effect. By using these road safety-related assessment tools in the preparation and facilitation of the decision-making process in Europe, an efficient road safety policy can be ensured.

Illustrating **best practice** for cost-effective road safety investments in Europe and worldwide is essential, as it may facilitate a better understanding of how road safety improvements have been made, either by the successful application of single infrastructural road safety measures or by integrated approaches that have proven to be effective. Based on an analysis of the relevant literature, results achieved in one situation can be used to forecast the effects of such measures when implemented under other, similar circumstances: thus, specific guidelines for ensuring the efficient application of road safety policies can be formulated.

However, it must be emphasised that the effectiveness of a particular type of development in one specific situation does not usually guarantee that it will be valid in all contexts. The implementation of that type of investment in other countries or areas may produce different results with varying degrees of success in accordance with the extent and duration of its implementation and specific national or local requirements. The choice of an investment or a series of investments should always be based on a road safety study conducted by specialists. Therefore, knowledge of the relative cost-effectiveness of road safety infrastructure investments can be very useful in the selection of appropriate solutions for different road safety problems, but only when a **thorough analysis on a case-specific basis** is also performed. Furthermore, it must be ensured that such analyses are carried out in accordance with recognised standard methodologies.

2.3 Efficiency-assessment methodologies

Road safety related assessment tries to enable a selection of the optimal road safety measure. This may be achieved through the application of two widely used efficiency assessment tools, the **Cost-Benefit Analysis** (CBA) and **Cost-Effectiveness Analysis** (CEA), which enable decision making and choice of the policy with the highest return in monetary terms. Cost Effectiveness analysis sequences the implemented measures, whereas Cost Benefit analysis admits additionally an evaluation of the rentability of measures. Road safety related assessment allows for the prioritisation of the road safety problems, the improvement of the road safety funding mechanisms by ensuring a more efficient allocation of public resources, but also enables target setting within the framework of a national or local road safety programme, using quantitative methods. Moreover, the application of Cost-Benefit and Cost-Effectiveness analyses also allows assessing the results of the systematic monitoring and controlling of road safety activities implementation, an essential step in a systematic evaluation process. The observation of safety plans or programmes should comprise the systematic recording of the activities and actions providing the decision-maker with necessary information, allowing re-planning, re-organising and steering the road safety activities.

2.3.1 Cost-effectiveness and Cost-benefit ratios

Cost-effectiveness and cost-benefit analyses are standardised techniques used for the evaluation of road safety investments.

The cost-effectiveness ratio of a road safety measure is defined as the number of accidents prevented by the measure per unit cost of implementing the measure (ROSEBUD, 2005):

$$\text{Cost - effectiveness} = \frac{\text{Number of accidents prevented by a given measure}}{\text{Unit costs of implementation of measure}}$$

The benefit-cost ratio of a road safety measure is defined as the present value of all benefits of the measure divided by the present value of implementation costs of the measure (ROSEBUD, 2005):

Benefit-cost ratio = Present value of all benefits/ Present value of implementation costs

$$\text{Benefit - cost ratio} = \frac{\text{Present value of all benefits}}{\text{Present value of implementation costs}}$$

Hence, in a cost-benefit analysis, effects are compared in monetary terms. It is also noted that a cost-benefit analysis requires the calculation of the cost-effectiveness components, as well as the calculation of additional ones. The monetary terms include accident costs, as well as a number of other factors, depending on the type and range of other effects considered, such as costs of travel time, vehicle operating costs, costs of air pollution, costs of traffic noise, and so on. In the following sections, a detailed presentation of the calculation of the various components is given.

In order to make the costs and benefits comparable, a conversion of the values to a certain time reference is required. Such an action needs a definition of the economic frame, i.e. the duration of effect (length of service life of the investment) and the interest rate, which are those commonly used for the performance of economic evaluations in the country.

In a basic case, where the benefits come from accidents saved only (and no influences on mobility or the environment are expected), the numerator of the benefit-cost ratio will be estimated as:

Present value of benefits = (Number of accidents prevented) × (Average accident cost) × (The accumulated discount factor)

In the above formula, the accumulated discount factor depends on the interest rate and the length of life of the measure.

2.3.2 Calculating safety effects

The accidents that are affected by a safety measure are referred to as "**target accidents**". Depending on the type and range of safety investment, a "target injury group", a "target driver population", and so on, may also be considered.

It is noted that there are no strict rules for this case. For global or area-wide investment, such as treatment of hazardous locations, traffic calming or speed limits, the target accidents group usually includes all injury accidents. For instance, however, for pedestrian facility treatments, the target accidents group would include pedestrian injury accidents. One should remember that, if a specific and not general accident group is considered, the related corrections need to be performed for the accident costs, as well.

In order to estimate the **number of accidents that can be expected to be prevented** per unit of implementation of a safety investment, two components need to be calculated: the number of target accidents expected to occur per year for a typical unit of implementation of the investment, and the safety effect of the investment on target accidents.

Number of accidents expected to be prevented = (Number of accidents expected to occur per year) × (The safety effect of the measure)

The most common form of a **safety effect** is the percentage of accident reduction following the treatment. The main source of evidence on safety effects is from observational before-and-after studies (Hauer, 1997). However, due to the diverse nature of road safety investments and the limitations of empirical studies, other methods for quantifying safety effects are also used. Those provide mainly theoretical values of the effects based on the relationships between risk factors and the effects.

More specifically, there are confounding factors which influence the number of road accidents and casualties and, therefore, should be accounted for in the estimation of a real safety effect of the treatment. These confounding factors are (Hauer, 1997):

- **Selection bias:** Road accidents have a random behaviour, for which it is possible to assume a given distribution of frequency (e.g. Poisson). Hence, in some periods, the values measured on given points of the network can be greater (or less) than the average values expected for those points. If the measurement leads to choosing those points for the treatments, a selection bias occurs and, in the measurements made after the treatments, an effect of decrease of crashes is registered (also known as "regression to the mean"), independent of the treatments.
- **Uncontrolled environment:** Road accidents occur in a setting, which, unlike a laboratory, is not 'controlled'. Therefore, for some types of road accidents, some medium-long term trends can be observed due to various safety features of vehicles or a change in driver habits. If a decreasing road accidents trend took place in the previous years, the reduction of road accidents after a treatment would probably have occurred even without the treatment.
- **Other external factors:** These can also affect the number of road accidents where a treatment took place; for instance, a reduction or an increase in traffic flows may bring about a variation in the number of road accidents, independent of the treatment.

In order to properly quantify the effects of a treatment, a simple before-and-after comparison is not sufficient, as it is necessary to compare the situation with the treatment ("**after**") to the situation that would have existed if the treatment were not applied. The latter presents a corrected value of a previously observed ("**before**") situation.

Determining what would have occurred in a site without the treatment is a critical part of the entire process and is performed in two steps: first, the determination of the correct "before" value (of the effect), which accounts for the selection bias and second, the determination of the correct "after" value without the treatment, accounting for the uncontrolled environment.

The Empirical Bayes method constitutes an effective instrument for the first step. A correction of "before" safety effects is performed with the help of reference group statistics, for each site in the treatment group. A detailed description of these techniques can be found in ROSEBUD (2004)

As for the second step (corrected value of effects without the treatment), two basic approaches are possible (ROSEBUD, 2004, Yannis et al, 2005):

- Using a **comparison group**, assuming that changes in the safety effect in the comparison group forecast accurately the changes that would have occurred at the treatment sites in the absence of treatment. The evaluation of the treatment effect is performed by means of the Odds-ratio, where for the "before" period the "corrected" effects numbers (from the first evaluation step) are applied.

In this case, the safety effect is estimated as:

$$\text{Estimated effect } (\theta_i) = [X_a/X_m]/[C_a/C_b]$$

where

X_a - the number of road accidents observed at the treatment area in the "after" period

X_m - the number of road accidents observed at the treatment area in the "before" period

C_a - the number of road accidents observed at the control group area in the "after" period

C_b - the number of road accidents observed at the control group area in the "before" period

The statistical weight of the estimate is then:

$$w_i = \frac{1}{\frac{1}{A^i} + \frac{1}{B^i} + \frac{1}{C^i} + \frac{1}{D^i}}$$

Where A, B, C, D are the four numbers of the odds-ratio calculation. The weighted mean effect is:

$$\text{Weighted mean effect (WME)} = \exp\left(\frac{\sum_i w_i \ln(\theta_i)}{\sum_i w_i}\right)$$

with 95% confidence interval for the weighed effect estimated as follows:

$$\text{WME} \exp \frac{z_{\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}, \text{WME} \exp \frac{z_{1-\frac{\alpha}{2}}}{\sqrt{\sum_i w_i}}$$

The applicable value of the safety effect, i.e. the best estimate of accident reduction associated with the treatment (in percents), is calculated as $(1-\text{WME}) \cdot 100$.

- Using **multivariate models**, which supply the expected number effects as a function of a series of physical and traffic parameters of the treatment sites and of general trends. The technique of generalised linear models (GLMs), with a Poisson or Negative Binomial distribution for the frequency of examined effects, is the most widely accepted today for this purpose and several methods for the development of such models are available.

It is emphasized that the safety effect of a measure is stated as available if the estimates of both the average value and the confidence interval of the effect are known. It is also necessary to ascertain that both the type of investment and the type of units for which the estimates are available, correspond to those for which the cost-effectiveness or cost-benefit evaluation is performed.

In practice, a correction due to selection bias is not always necessary. For example, a correction is not performed where a large number of sites are treated and they are selected without consideration of previous crash experience (ROSEBUD, 2004).

In the absence of local values for a road safety investment (as can be the case in ex-ante evaluations), the summaries of international experience are often used.

Finally it is noted that a **"positive" or "negative" safety effect** depends on the consideration of the safety effect in the analysis. For instance, in an analysis estimating the percentage of accidents reduction, a positive percentage indicates a reduction of accidents and a negative percentage reflects an increase of accidents. On the contrary, in an analysis estimating the percentage change in the number of accidents, a negative percentage indicates a reduction of accidents and a positive percentage indicates an increase of accidents.

2.3.3 Calculating costs

2.3.3.1 Accidents costs

Accidents cost calculation includes three major cost items as follows (Alfaro et al, 1994, Yannis et al. 2005):

- **Material damage costs**
- **Generalised costs**, including administrative costs (Police costs, Fire brigade costs, First aid and transportation costs, Insurance companies cost, Court costs, Hospital treatment and rehabilitation costs) and costs of lost productive capacity (Lost production output)
- **Human costs**, based on the Value of Statistical Life and the loss of quality of life.

The relative shares of these three elements differ between fatalities and the various degrees of injuries, and also differ among countries. Especially as regards human costs, a lot of uncertainty exists with respect to international comparisons. Most countries have calculated their own official values of the Value of Statistical Life, which corresponds directly to the cost of a fatality. However, different methods are used and these can be divided into two large groups (ROSEBUD, 2004):

- Behavioural approaches, based on the **willingness-to-pay** technique, a survey-based technique in which values are determined on the basis of the stated amount individuals are willing to pay in order to reduce the risk of pain and grief caused by damage and death in road accidents, beyond the costs of medical expenses and reduced income-earning ability.
- Non behavioural approaches, in which values are normally taken (directly) from market prices and from public accounts, whilst individual-based valuation of lost quality of life are disregarded.

Table 2.1 below summarises a set of national human costs values, as presented in ROSEBUD (2004).

Table 2.1. Official national values of human costs (1000€, 2002 prices)

Country	Fatality cost	Serious injury cost	Slight injury cost	Valuation method
Czech Rep.	263	91	10	Non-behavioural
Hungary	276	25	3	Non-behavioural
Germany	1,257	86	4	Non-behavioural
France	1,500	150	22	N/A
Netherlands	1,741	256	38	Behavioural
Finland	1,934	261	50	Behavioural
Switzerland	1,912	169	18	Behavioural
Sweden	1,954	349	20	Behavioural
UK	2,107	237	18	Behavioural
Norway	3,016	474	41	Behavioural

A detailed discussion of the features, advantages and limitations of each approach falls beyond the scope of the present report. However, it is worth mentioning that the UNITE project

(Nellthorp et al, 2001) proposed a set of recommended values for human costs, as presented in the following Table 2.2.

Table 2.2. Official national values of human costs (thousand €, 2002 prices)

Value of Statistical Life (UNITE2001, thousand € in 1998 prices)		
EU-15	official	Recommended
Belgium	0,40	1,67
Denmark	0,52	1,79
Germany	0,87	1,62
Greece	n.a.	1,00
Spain	0,70	1,21
France	0,62	1,49
Ireland	1,04	1,63
Italy	n.a.	1,51
Luxembourg	n.a.	2,64
Netherlands	0,12	1,70
Austria	1,52	1,68
Portugal	0,04	1,12
Finland	0,89	1,54
Sweden	1,48	1,53
United Kingdom	1,53	1,52

At European Union level, the “1 Million euro rule” is still used to put a value on the prevention on casualties. This was introduced by the European Commission in its Road Safety Programme 1997-2001 to help select effective road safety measures (European Commission, 1997) and implies that a road safety measure can be considered for implementation when for every million euros spent on it, at least one death is prevented. The economic damage of a fatality and also a certain proportion of the damage resulting from (serious) injuries and from accidents with only property damage are taken into account for determining this amount. This is based on the fact that, on average, for every fatality prevented there will also be a number of injury accidents and an even greater number of material damage accidents (Wesemann, 2000).

Additionally, based on a review made by de Blaeij et al (2004) and a paper by Tecl and Konarek (2006), the following Figure 2.1 presents the official monetary valuation of preventing a road accident fatality in a number of countries.

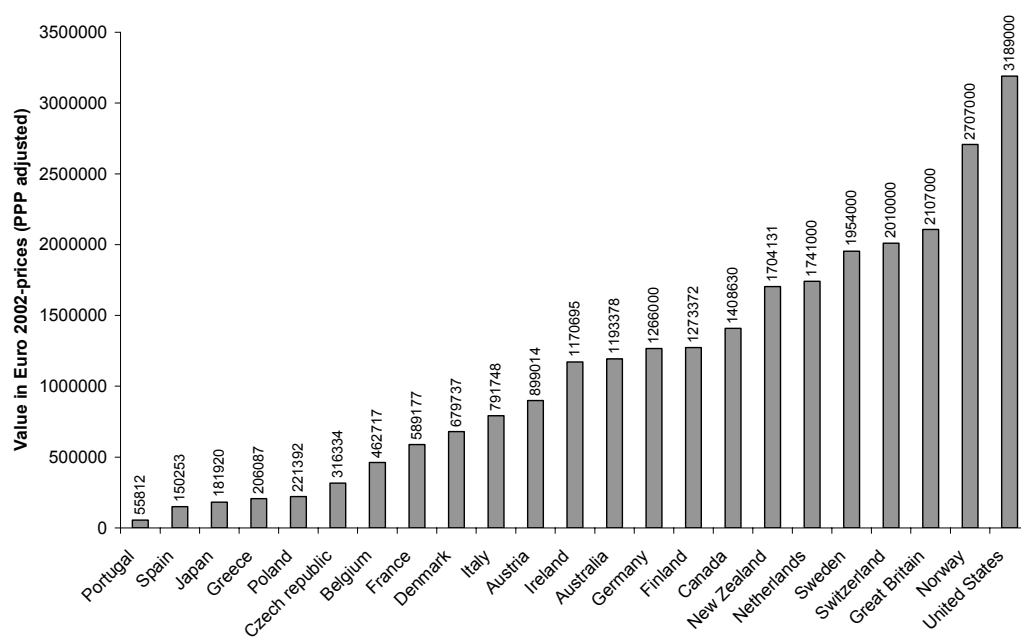


Figure 2.1. Official monetary valuation of a road accident fatality in selected countries - Euro in 2002-prices

As it can be seen from the above Figure, the valuations vary substantially among the countries. An interesting pattern is that some of the countries that have a good safety record, such as Norway, Great Britain, Sweden and the Netherlands, assign a high monetary value to the prevention of a traffic fatality, contrary to some countries with a rather low road safety level, such as Portugal, Spain and Greece, which assign a low monetary value to the prevention of a fatality. Generally though, it is acknowledged that the values of human cost are determined by two main factors: The estimation method used, as values based on the willingness-to-pay approach tend to be about twice as high as values not based on the willingness-to-pay approach and also the level of real income in a country, as in general, lower values are observed in countries that have a relatively low gross domestic product per capita, whereas higher values are found in the richer countries.

Moreover, the TEN-STAC project proposes a set of fixed proportions of the Value of Statistical Life to be applied for serious and slight injuries, namely 13% and 1% respectively (TEN-STAC, 2003, quoted by Gaudry, 2004).

2.3.3.2. Implementation costs

In order to calculate the implementation costs of a road safety investment, one needs a definition of suitable **units of implementation** for the investment, as well as an estimate of the costs of implementing one unit of the investment. In the case of infrastructure investment, an appropriate unit will often be one kilometre of road or one junction. In the case of area-wide or more global investments, a suitable unit may be a typical area or a certain category of roads, and so on (ROSEBUD, 2004).

The **implementation costs** include the social costs of all means of production (labour and capital) that are employed to implement the investment and they are generally estimated on an individual basis for each investment project. As no strict rules are available on the issue, in a cost-benefit analysis all the components of the implementation costs should be outlined and explained. Typical costs of engineering measures, which are recommended for cost-benefit evaluations in each country, are desirable. The implementation costs should be also converted to their present values, which include both investment costs and the annual costs of operation and maintenance.

However, apart from the impact to the number of accidents, all other impacts of a road safety infrastructure related investment should also be identified and valued in monetary terms, and subsequently be considered into the cost-benefit analysis. Such impacts would normally include changes in travel time, changes in vehicle operating costs, changes in noise and air pollution and comfort during travelling.

3 REVIEW OF ROAD SAFETY INVESTMENTS

In the previous Chapter, the need for quantitative results from efficiency assessment of road safety investments, and their incorporation into national road safety plans and strategies were examined. In recent years, important and useful work in producing and summarising efficiency assessment results for road safety investments have been done. However, in several cases, the available information and results are limited: this is partly due to the general complexity of efficiency assessment and partly due to the lack of data.

In this chapter, the results of an **exhaustive review of the existing efficiency assessment issues and results for road safety infrastructure investments** are presented. The analysis aims to describe the most common and important road safety investments and to summarise the existing research findings with regard to safety effects, non-safety effects, and cost-effectiveness assessment. It is noted that, whenever possible, cost-benefit ratio results were examined.

Apart from the availability of information in international literature, the selection criteria for the investments examined were as follows:

- investments that are mainly related to road infrastructure,
- investments that are common among EU countries and frequently implemented,
- balance between investments of different size, implementation cost, and scale of implementation,
- investments that are comprehensive and concise. A complete description of the basic components for the efficiency assessment of the investment should be available.
- investments for which adequate information was very difficult or impossible to obtain are not retained in this guide, despite their ad hoc implementation and assessment in specific cases.
- investments included in the previous CEDR report and in Questionnaire 2 of task group O7 were examined. In general, previous CEDR work was used for this synthesis wherever possible.

The types of investment selected fall within **five broad categories**: general, motorways, rural roads, junctions, and urban areas. The complete list of investment categories and areas is presented below (specific investments within each area are given in brackets):

3.1 General:

- road safety impact assessments
- road safety audits
- network safety management
- safety inspections

3.2 Motorways:

- development of motorways
- development of interchanges

3.3 Rural roads:

- horizontal curvature treatment (increasing curve radii, introduction of transition curves, reducing the frequency of horizontal curves, superelevation treatment)
- vertical curvature treatment (reducing gradient, reducing the frequency of crest or sag vertical curves, improvement of sight distances)
- cross-section treatment (increasing the number of lanes, increasing lane width, introduction of shoulder, increasing shoulder width, introduction of median, increasing median width, introduction of 2+1 roads)
- roadside treatment (flattening side slopes, establishment of clear zones, implementation of safety barriers, replacing safety barriers to meet the EN 1317 standard)
- speed limits (changing from unrestricted speed to speed limit, lowering existing speed limit, creation of speed transition zones)
- traffic control and operational elements (traffic signs (regulatory), traffic signs (warning), traffic signs (guide), delineators and road markings, raised road markers, chevrons, post-mounted delineators, rumble strips)
- eSafety systems (navigation routing, weather info VMS, congestion info VMS, individual info VMS, vision enhancement systems)
- road surface treatment (ordinary resurfacing, improving road surface evenness, improving road surface friction, improving road surface brightness)
- lighting treatment (implementation of artificial lighting, improving existing lighting)
- rail / road crossings treatment (introduction of rail/road grade crossings, protection of rail/road level crossings)

3.4 Junctions:

- development of roundabouts
- junction layout (junction channelisation, junction staggering, junction realignment)
- traffic control at junctions (implementation of 'yield' signs, implementation of 'stop' signs, implementation of traffic lights, improvement of existing traffic lights)

3.5 Urban areas:

- traffic calming schemes
- development of bypasses
- improvement of land use regulations

It is noted that the above classification of road safety investments is not rigid: on the contrary, some investments may be applicable to more than one area. For example, road markings and traffic signs can be implemented both at junctions and on rural roads. However, these common investments are classified under their main or primary area of implementation.

For each of the above road infrastructure-related investment areas, the presentation included the following components:

- description of the investments
- safety effect of the investments
- other effects
- costs
- cost-benefit analysis results

Moreover, in each case, methodological issues concerning cost-effectiveness calculations were also highlighted. Finally, numerical results relating to safety effects or cost-benefit ratios were provided (where available) and their reliability was assessed.

3.1 General

Road infrastructure and design are a contributing factor in approximately one out of three road accidents (Sabey and Taylor, 1980). However, the general trend is to decrease national funding for road infrastructure. Many national road authorities are in a dilemma because they have to provide to the road users who pay more and more attention to the quality and level of safety of roads, an infrastructure corresponding to the latest road safety standards under budgetary constraints. In order to increase the safety of road infrastructures, a relevant EU-Directive was proposed, introducing a comprehensive system of road infrastructure safety management, which focuses on the following four general procedures (European Commission, 2006):

- (1) **Road safety impact assessments**
- (2) **Road safety audits**
- (3) **Network safety management**
- (4) **Safety inspections**

The setting up of appropriate procedures is an essential tool for improving the safety of road infrastructure within the road network, as it explicitly limits the requirements to a minimum set of elements necessary to achieve a safety effect that has been shown to be effective. The objective of the proposed directive is to ensure that safety is integrated into all phases of planning, design and operation of road infrastructure, with emphasis to the Trans-European Network (TEN-T), but also that it is regarded in its own right in parallel with economic and environmental analysis. Moreover, it will ensure that road infrastructure authorities are aware of the appropriate guidelines, training and information required to increase safety in the road network to the best benefits of road users.

These procedures, which can be considered as general measures to improve infrastructure road safety, already exist and are applied at varying degrees in some Member States. However, the aim of this directive is to extend these measures to the whole European Union, and especially to the Trans-European Network (TEN-T), without defining technical standards or requirements, but leaving the Member States free to keep already existing procedures or to introduce their own. The application of the comprehensive package of measures will make sure that road safety is included and considered in the whole life-cycle of a road, from planning to operation (European Commission, 2006). The same procedures can be applied to any type of road network at a different implementation level, varying according to the examined type of infrastructure.

3.1.1 Road safety impact assessment

Description

Approval procedures for new roads or rehabilitation works on the existing road networks take into account economic data, environmental effects and traffic impacts, but they very rarely consider the safety implications of a project. Road safety impact assessment concerns a **strategic comparative analysis** of the impact of new road or a substantial modification to the existing network on the safety performance of the road network. Road safety impact assessment should demonstrate, on a strategic level, the implications on road safety of different planning alternatives of an infrastructure project, before this is approved. Therefore, road safety impact assessments take place at an early planning stage, allowing the results of the assessment to influence the further planning process, as in the case of environmental impact assessment. Moreover, they should be carried out on all transport policy measures having an influence on road safety, including e.g. infrastructure investments, standardisation, pricing, etc (European Commission, 2006).

The main elements that a road safety impact assessment should look at are: the clear definition of the problem, the recording of the current situation and “do nothing” scenario. Subsequently, it should define the road safety objectives, consider the analysis of impacts of the proposed alternatives (including cost-benefit analysis) and compare between them. Based on the outcome of this comparison, the best possible solution will be identified. During the implementation of a road safety impact assessment reduction targets regarding casualties and accidents against “do nothing” scenario are taken into account, as well as route choice, traffic patterns and presence of intersections with the existing networks (exits, junctions, level crossings). The impact on vulnerable users (pedestrians, cyclists and motorised two wheelers) is carefully measured, and the traffic flows (number of vehicles by vehicle type) are examined.

Other effects and costs

As the **road safety impact assessment** is produced in parallel with the approval procedure and the design process of the road, no additional delays in the approval procedures are usually expected. A rough estimation of the costs for the development of road safety impact assessments can be made considering the costs of the analogous environmental impact assessments. In general, impact assessment costs amount to less than 0.5% of the overall capital cost of a construction project, with costs in excess of 1% being the exception. For projects with capital costs of more than 100 millions €, the respective impact assessment costs may be reduced to 0.2% of the overall project implementation cost.

3.1.2 Road Safety Audits

Description

Road Safety Audits consist of a set of regulations and guidelines, usually created by the National Road Authorities; these regulations mainly cover the road design, traffic control and maintenance and aim at ensuring a high road safety level. They are intended at detecting and correcting deficiencies in the above areas (Elvik, Vaa, 2004), but also at ensuring that measures to eliminate or reduce road safety problems are considered fully (Austroads, 2002).

Road Safety Audits may include a variety of actions, usually formulated as a set of checklists, aiming to investigate a broad range of issues ranging from development and implementation plans to specific road and traffic control facilities. According to the previous work of CEDR (2006), road safety audits are a commonly accepted road safety measure, as they are performed in 58% of the CEDR Member States. Only 8% of the countries which do not have a RSA programme at present do not plan to introduce one in the future and in general, this issue is a top priority for 23% of the countries, a medium priority for 43% of the countries, and of low priority for the rest.

Safety effects

Very few studies have evaluated the safety effect of Road Safety Audits; studies mainly focus on particular sets of actions that were initiated through the audits on specific road networks and consider accident reduction as the main safety effect, even though more benefits may arise from the implementation of road safety audits. Most cases concern treatments aiming to improve compliance with guidelines. In general, positive effects of the actions were identified; however most studies admit a lack of statistical validation of the results.

In ROSEBUD (2006) it is noted that the effects of road safety audits depend on the implementation of the recommendations made by the auditor.

Other effects

No effects of Road Safety Audits on mobility or the environment have been identified. However, the reduced whole life project costs, the enhancement of road safety engineering, the reduced need for remedial works after new schemes are built and eventual safety improvements to standards and procedures could also be taken into account as benefits from implementing road safety audits (Austroads, 2002).

Costs

The costs of Road Safety Audits fall under two main headings: the costs of the Audits themselves and the costs of the actions resulting from them. The first type depends on the National allocation of resources and the type of Audit and as it mainly concerns the design stage of an intervention, it is rather low. The second type may vary significantly in relation to the type of proposed treatment (infrastructure- or traffic-control-related) and can be broken down into redesign costs and possible increased project costs due to additional design or resulting delays. The thematic network RiPCORD-iSEREST made a survey on audit costs estimations in the countries where audits are already performed. The results of this study show that in those European countries audit costs range between 600 and 6.000 € per stage. In general, the estimations in the different countries indicate that audit costs are far less than 1% of the implementation cost of the whole project (RiPCORD – iSEREST, 2007).

Cost-benefit analysis (CBA) examples

One example of overall assessment of the Auditing framework, which has been published (Jørgensen and Nilsson, 1995), concerns the Danish case in which a number of Road Safety Audits and the resulting treatments were found to be highly cost-effective in relation to both the 1st year rate of return and the lifetime of the treatments. In 1998, Surrey County Council compared before and after road accident statistics for a sample of 19 audited schemes and 19 non-audited schemes and concluded that the audited schemes achieved an average casualty reduction per year of 1.25 compared to a reduction of 0.26 for the non-audited schemes (Surrey County Council, 1998). Moreover, the Transport Research Laboratory conducted a study on behalf of the UK Highways Authority (Wells, 1999), which compared the costs of implementing road safety audit recommendations at the design stage of a project, with the costs of introducing changes after the project was constructed. Effectively the study investigated the potential disadvantages of not conducting road safety audits, revealing that the average saving from implementing changes at the design stage rather than after the project implementation was 11,373£.

Other studies focusing on particular types of treatments resulting from Road Safety Audits also indicate positive results. A comparative assessment of studies on the effectiveness of Road Safety Audits has shown that the benefit to cost ratio averages typically between 10:1 and 20:1 (ETSC, 1997), whereas the benefit to cost ratio of the implementation of Road Safety Audits in Germany was estimated from 4:1 to 99:1 (BASt, 2002). Finally, results from Denmark (Herrstedt, 2000) reveal a less satisfactory cost-effectiveness of around 1.5:1.

The effectiveness of road safety auditing is a “derived effectiveness” – depending on the effectiveness of the implementation of the proposed measures (ROSEBUD, 2006)

3.1.3 Network safety management

Network safety management is a relatively new practice, which is based on the analysis of the existing road network in order to identify the parts with the higher accident density and the road safety measures that have the highest accident reduction potential, i.e. it will consider parts of the network where, respectively, accidents occurred most frequently during previous years and accident cost reduction potential is the highest, by targeting remedial treatment. According to a previous work of CEDR (2006), the majority of the CEDR countries (69%) have been managing high-risk sites for some time, i.e. the UK have been implementing this measure since the 1960s, and in half of the countries network safety management is under the main responsibility of the road directorate. This measure is a top priority for about two thirds of the countries and funding varies among the countries but is usually based on the national road budget (CEDR, 2006).

Identification of high-risk road sections is necessary to target action on stretches of road where high numbers of fatal and severe accidents occur or can be expected. Safety effects are expected to be maximised during the first years of a high-risk site management programme. This is the reason why infrastructure authorities should mobilise the critical resources in staff, know-how and finance to substantially and quickly reduce the number of serious and fatal road accidents. The identification of high-risk road sections takes into account at a minimum the number of fatal and severe injury accidents that have occurred in previous years per unit of road length and, in case of intersections, the number of such accidents per location of intersections. Once high-risk road sections or black spots have been dealt with, the safety quality of the whole network will be improved. Assessments will range from identifying and treating accident patterns at single high-risk sites or black spots to understanding and managing safety over whole routes.

1. Identification of sections for further analysis is another important part in network safety management. This further analysis can include the calculation of basic accident cost rates for a best practice road section of a certain category, in accident cost per kilometre or for each section of a certain road category, calculation of the accident cost reduction potential per kilometre, as the difference of the actual accident cost per kilometre for the section considered and the basic accident cost rate.

As network safety management is an ongoing procedure that takes place during the entire operational stage of a road, the coordinates of the examined road section should be recorded and be accompanied by a reference to a possible previous report on the same road section. Additionally, an analysis of the accident reports should be considered, taking into account the number of fatal and serious injury accidents in the three previous years.

The proposed set of remedial measures can be distinguished into short and long-term, according to the time of implementation and the expected benefits. More specifically, a set of remedial measures for implementation within one year could concern removal or protection of fixed road side obstacles, redefinition of the speed limits and intensification of the local speed enforcement, visibility improvement under different weather and light conditions, improvement of readability and position of road markings (incl. application of rumble strips), signs and signals and interventions on the grip / roughness of pavements.

A set of long-term remedial measures for implementation within more than one year concern for example redesign of road restraint systems, improvement of median protection, junction improvement including road/rail level crossings, change road geometrical characteristics such as alignment, width of road (addition of a hard shoulder), installation of traffic management and control system, investigation of potential conflict with vulnerable road users, upgrading the road to current design standards and restoring or replacing of pavements.

An efficient network safety management programme is mainly performed on the basis of accident records and inspections and usually has a high potential immediately after its implementation. Its organisational costs can be assumed comparable to costs of routine road safety inspections, however they differ among the countries according to the scale of implementation. In Germany, improvements in the road network safety are carried out in areas which are considered to have a high frequency of serious accidents. The basis for this work is the German guideline for safety analysis of road networks. The accidents per kilometre of road are converted into annual economical loss to get an indication of cost savings had the road been built according to national highway design standards. In Finland network safety management consists in the monitoring of longer road sections (usually 20-50km), which are classified according to their fatal accident density (defined as fatalities/100km/year). Investments are implemented to improve safety of roads according to this fatal accident density. In the UK, the Highways Agency has introduced a road safety strategy with supporting documents for the safety management of the trunk road network, such as an operational guide. Network safety management relies on availability of relevant accident data, understanding of network effect (not just high-risk road sections) and the use of a systematic approach to planning. Priorities are to encourage traffic onto appropriate roads with appropriate speed limits.

3.1.3.1 Treatment of Hazardous Locations (black spots)

Description

Treatment of hazardous locations (black spots) is a very important part of the overall network safety management, as there is often a tendency for road accidents to cluster at specific places. A concentration of accidents at a specific spot may be partly due to inappropriate road design or inappropriate traffic control at that location. In this case, the clustering of road accidents can be avoided or reduced by improving road design or traffic control (Elvik, Vaa, 2004). The majority of these hazardous locations are situated at or near junctions.

The definition of hazardous locations may vary in different countries or in different analyses. For instance, in some cases hazardous locations are defined as road sections with a maximum length of 100 metres, whereas in other cases black road sections are considered, whose length may reach 1 kilometre.

Hazardous locations identification methods also vary significantly. In some cases they are identified on the basis on road accident frequencies. However it is by far more correct to consider the related accident rates (e.g. accidents per million vehicle-kilometres), which take into account the degree of use of the road section.

Treatment of hazardous locations may be carried out at national, regional (axis or municipality) or local (spot-specific) level and may concern a variety of isolated or combined improvements.

Safety effects

An important number of studies have identified positive effects of treatment of hazardous locations on road safety. However, not all of them account for two important factors: regression-to-the-mean and accidents migration. The first one refers to the fact that the numbers of accidents "before-and-after" the treatment should be examined in relation to the number of accidents that would have occurred if the treatments had not taken place. The second one refers to the fact that the number of accidents at places close to the related sites may increase after the treatments.

Other effects

Depending on the type of treatments, mobility may be improved (e.g. development of roundabouts, road surface treatment, implementation of traffic control) or impeded (e.g. reduction of speed limit). Accordingly, if the treatments bring a significant modification of traffic volumes and speeds (e.g. less or more congestion), environmental effects should be considered.

Costs and cost-benefit analysis (CBA) examples

Depending on the type and the implementation level of the treatments, the related costs may vary significantly, ranging from thousand to million Euros. However, there are many cases where hazardous (black spot) locations can be initially treated using low cost road safety measures.

Although safety and other effects and costs may vary significantly, as explained above, treatment of hazardous locations are usually highly cost-effective. However, no general rule can be formulated. An overall picture can be created by considering the cases of isolated treatments, which are presented in the following sections. For example, hazardous locations treatment in Switzerland was evaluated within the VESIPO project (2002) and a cost-benefit ratio of 13:1 was obtained, Newstead and Corben (2001) evaluated an extensive hazardous location treatment program in Australia in the period 1992 - 1996 and estimated a cost-benefit ratio of 4:1 to 5:1.

3.1.4 Road safety inspections

Description

Road safety inspections concern a periodical safety review of a road in operation. They are considered as part of the regular road maintenance and allow for detecting and reducing in a preventive way the risk of accidents through application of cost-efficient measures. Safety inspections can be broken down into regular and ad-hoc and as a preventive measure should assume a more important role. Regular inspections are an essential tool for preventing possible dangers for all road users, including vulnerable users, and can also play a role in the case of road works. They are required to identify transient changes affecting the condition and visibility of the signs and markings for example, but are also necessary to inspect and remedy safety deficits in locations without a past record of high accident numbers. Such safety inspections are carried out periodically in the context of a safety programme and target sensitive points like road works, level crossings, signing, tree lines and night visibility.

The road safety inspection procedure does not require data input and the investigators need expert qualification and experienced in road safety. Their evaluation of the “risk features” of the road and its environs is not only an identification of the hazardous situation, but also enables a further risk analysis to indicate both where accidents are likely to occur and which action is appropriate (PIARC, 2007). The risk analysis approach will establish links between certain design elements and accident occurrence in order to compare route sections with desired safety principles. Accident reports can also play a crucial role in improving road infrastructure, as they must identify relevant accident types. This information will be made available to allow the identification of high-risk sites or black spots, as well as the selection and ranking of effective remedial measures.

Road safety inspections are performed in 42% of the CEDR countries and for about one quarter of the countries the measure has top priority. 12% of the countries perceive it as a low priority measure.

Costs

With reference to road safety inspection costs in the European countries, where inspections are carried out on a regular basis, costs can range between 600 and 1,000 € per km of motorway. Considering the roads where the EU-Directive application will be mandatory (the EU-25 Trans-European road network, having an overall length of approximately 85,000 km in 2005), one can estimate that the overall cost of the inspection of the whole network will range between 50 and 85 millions €. Consequently, for a large sized country, having about 5,000 km of Trans-European road network on its territory, this means costs for inspections ranging between 3 and 5 millions €.

3.2 Motorways

3.2.1 Development of motorways

Description

Motorways are designed to carry heavy traffic at high speed with the lowest possible number of accidents. They are also designed to collect long-distance traffic from other roads, so that conflicts between long-distance traffic and local traffic are avoided (Elvik, Vaa, 2004). According to the common European definition, a motorway is defined as "*a road, specially designed and built for motor traffic, which does not serve properties bordering on it, and which: (a) is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other, either by a dividing strip not intended for traffic, or exceptionally by other means; (b) does not cross at level with any road, railway or tramway track, or footpath; (c) is specially sign-posted as a motorway and is reserved for specific categories of road motor vehicles*" (Eurostat / UNECE / ECMT, 2003). Urban motorways are also included in this definition. However, the respective national definitions and the type of roads covered may present slight differences in different EU countries (NTUA, 2005).

Safety effects

Although the main purposes for motorways development are usually other than safety purposes, **motorways** have much lower accident rates compared to other interurban and rural roads. According to road accident data retrieved by the CARE database, in 2005 the percentage of road fatalities on motorways, comparing to the ones on the remaining road network, in 14 EU countries varied from 2.6% for Finland to 14.8% for Belgium. The respective average percentage for the 14 EU countries was 8%, whereas on average, road fatalities on the remaining road network constitute 92% of the overall road fatalities (CARE database, data retrieved on 7/3/2007). However, comparison of the absolute figures of road fatalities does not always provide the appropriate insight to the road safety problem, as exposure data should also be used, in order to develop appropriate road safety risk indicators. This exposure data may include the number of vehicle-kilometres travelled by road network type (motorway and other types), or the length of the road network (by type of road network). However, complete and reliable exposure data is not available for most EU countries (NTUA, 2005). When a new motorway is constructed, the reduction of the total number of accidents, but also the severity reduction of the accidents are significant comparing to the respective rates on the other roads, thus the motorways are considered to be the safest roads, especially when compared to urban and rural roads. There are though some studies indicating that the benefit deriving from the development of a motorway is not as large as would be expected mainly due to two reasons: Firstly, not all traffic shifts from existing roads to the motorway and secondly, the motorway generates new traffic, absorbing a possible latent demand due to congestion of the existing roads. On the other hand it is a fact that in many EU countries, only a small percentage of the road network are motorways, however they bear an important amount of the mobility demand of the countries. Consequently, it is evident that the above mentioned 8% fatality rate on motorways in 2005 is an excellent record.

Most studies report a positive effect of new motorway development on road safety. The magnitude of the effect depends on the distribution of traffic between the new motorway and the existing roads and on how large the induced traffic is. According to the literature, an average reduction in the number of injury accidents of 7% (from 4% to 9%) can be expected when a new motorway is constructed (Elvik, Vaa, 2004)

Other effects

The development of motorways has a positive effect on motor vehicles mobility, bringing an important improvement in travel speeds and travel times. However, in some cases there may be relatively limited environmental issues, such as the intrusion into the landscape (e.g. bridges) and an increase of noise and pollution due to the increased travel speed.

Costs

Even though the implementation and maintenance costs of motorways vary significantly between the countries, in some cases also due to the different tendering systems, they are usually high, comparing to the implementation costs of other road safety road infrastructure related initiatives.

Cost-benefit analysis (CBA) examples

Cost-effectiveness of motorways also varies from case to case, especially due to the different implementation costs. In most cases, though, CBA results reveal relatively small ratios for new motorway development comparing to respective ratios regarding other road safety investments, mainly due to the very high implementation costs. However, even these ratios are considered as adequate to support the decisions for motorway development or the upgrade of existing rural network into motorways and apart from the strict financial criteria, the significant social benefits for the road users can enhance the investment's effectiveness and should also be taken into account by the appropriate authorities.

- The upgrade of part of the interurban road network of Greece into motorways in the early 90s was evaluated in terms of safety effects only. A cost-benefit ratio of around 2:1 indicated that the safety effect alone could justify motorways development (Yannis et al. 2005)

3.2.2 Interchanges

Description

Interchanges are junctions where the primary traffic streams are segregated from each other by being placed on separate levels, in order to improve traffic flow and reduce the chances of conflict between different traffic streams. Intersections can be fully or partially grade-separated, according to the remaining number of at-grade crossings of traffic streams (Elvik, Vaa, 2004). Different types of intersections exist, such as diamond interchanges, trumpet interchanges and full or partial cloverleaf interchanges, as shown in Figure 3.1.

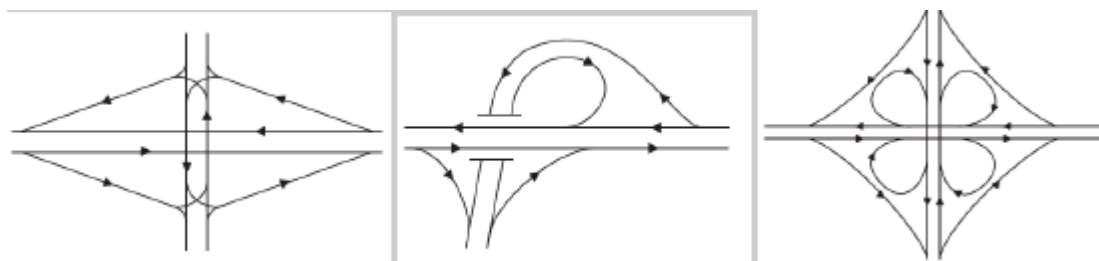


Figure 3.1. *Diamond, trumpet and partial cloverleaf interchanges*

A number of interventions can also be implemented to existing interchanges, in order to improve their safety performance, such as reconstruction of merge and diverge areas, defined as "*portions of the highway at an interchange where vehicles entering and exiting must change lanes to continue travelling in their desired direction*", improvement of interchange ramp terminals, which are defined as "junctions with a surface street to serve vehicles entering or exiting a freeway" (TRB, 2000), lengthening of acceleration and deceleration lanes to the ramp terminal intersection.

Additionally, there are various traffic control devices and operational schemes that can be employed at interchanges and interchange ramp terminal intersections. Such devices include intersection signalisation, ramp metering, signage including overhead signs, roadside signs with retro-reflective materials or illuminated and other guidance signs such as street names or route numbers, pavement markings and markers, and delineation, especially when applied at entry and exit points of an interchange.

Safety effects

The safety effects deriving from the introduction of a new interchange or the replacement of a level crossing have been the subject of a number of studies in several countries, mainly in relation to roads that are not motorways. Interchanges appear to be safer than crossroads, as a 50% decrease in the total number of road accidents in the area of the crossroads was observed when a grade-separated interchange was implemented.

There are a couple of issues that need to be considered when estimating the safety effect of **replacing a junction by an interchange**. First, it is necessary to include the numbers of accidents that occur on ramps of the interchange. Several studies consider an "equivalent ramp length" in the junction area (e.g. on the junctions arms), in order to account for the length of approach to the junction. This approach usually leads to higher safety effects; however, as ramps are new elements of the road in interchanges, the consideration of the "equivalent ramp length" leads to an overestimation of the safety effect. In most existing studies, where accidents on ramps are included but no "equivalent ramp length" is taken on the junctions arms, it is deduced that an important safety effect is obtained when crossroads are replaced by interchanges. On the other hand, no consistent pattern is identified when T-junctions are replaced by intersections.

Moreover, a number of studies deal with the safety effect of modifications on the intersection design. Improving the design of an intersection can bring important safety benefits, especially when the modifications aim at reducing ramp curvature, achieving a more self-explaining design and providing appropriate length and gradient for acceleration and deceleration. In particular (Elvik, Vaa, 2004):

- Diamond interchanges appear to be the safest form of interchange, due to their simplicity, the fact that they have straight ramps and that usually the secondary road is situated above the main road. According to relevant studies, the safety effect deriving from the implementation of Diamond interchanges comparing to other types of interchanges may vary between 6% and 39% decrease on the total number of road accidents, according to the compared type of interchange.
- Interchanges where the secondary road is situated above the main road appear to provide safer conditions for acceleration / deceleration and thus, may results to a 4% decrease on the total number of road accidents in certain cases.

- Reducing ramps curvature appears to have the highest safety effect amongst the various interchange design modifications, as a reduction on the total number of road accidents of around 20% is recorded.
- Extending the acceleration/deceleration length is also associated with safety benefits, which is significant according to relevant studies (a 7% - 11% decrease on the total number of road accidents by extending the acceleration/deceleration lanes by about 30 m.)

As it can be seen from the above mentioned examples, most studies examine total number of road accidents (including material damage only accidents), not allowing to assess the safety effect in relation to accidents severity.

Other effects

Interchanges have a positive effect on mobility and travel times. One could consider negative environmental effects due to the grade separation (e.g. more space required), but no studies have been able to quantify such an effect.

Costs

The implementation costs of interchanges are usually high but may vary significantly among different countries and / or different sites, not allowing for a general figure to be suggested. The implementation costs for modifying the design of an interchange are subject to ever higher uncertainty. However, the improvement of intersection signalisation and the implementation of appropriate signage and delineators could improve the road safety level of interchanges at a lower cost.

Cost-benefit analysis (CBA) examples

The introduction of an interchange in replacing a level junction does not always appear to be cost-effective, due to the increased implementation costs, together with the local nature of the intervention. An increase in interchanges efficiency can be obtained in the framework of axis- or area-wide upgrade of the existing road infrastructure e.g. introduction of motorway replacing existing rural or interurban road network.

3.3 Rural roads

3.3.1 Horizontal Curvature treatment

Description

The majority of accidents on horizontal curves concern single vehicle run-off accidents and head-on collisions (Torbic et al., 2003). Horizontal **curves radius** plays an important role in road safety. Curves of low radii lead to road safety problems. The general form of this relationship, as confirmed from an exhaustive literature review by Hauer (1999) is presented in the following Figure 3.2. Additionally, small angles (SHOULD THIS BE 'small radii') with sufficient sight distance are recommended to ensure design consistency (Al-Masaeid et al. 1999).

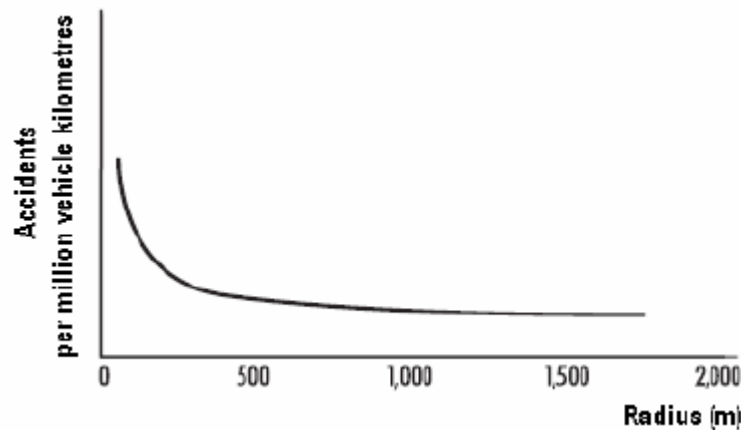


Figure 3.2. Accident risk in relation to horizontal curve radius (Hauer 1999, PIARC 2003)

Moreover, a **transition curve** should be constructed in horizontal curves, designed as a clothoid (i.e. a curve whose radius decreases linearly as a function of the arc length), so that drivers can follow the curve by turning the wheel at a constant rate in the direction of the curve and avoid thus any abrupt movement (Elvik, Vaa 2004).

The **frequency of horizontal curves** along the alignment plays an important role in road safety (Matthews, Barnes, 1988). A single curve of low radius after a long straight section is of higher risk than a set of consecutive curves of similar radii. The transition to sharper curves therefore should be carried out by a progressive reduction of radii along sequential curves (Figure 3.3 - Lamm et al. 1999).

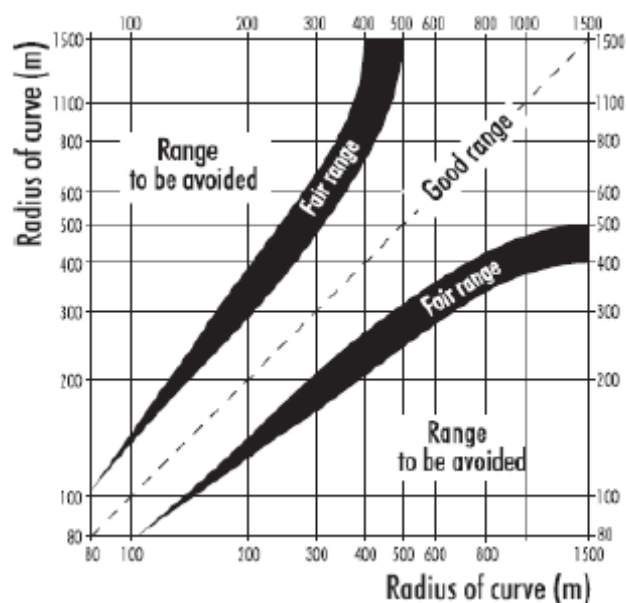


Figure 3.3. Tuning curve radii along sequential horizontal curves (Lamm et al. 1999)

Superelevation is defined as a transverse incline of the road toward the inside of a horizontal curve (Figure 3.4). It slightly reduces the friction needed to counter the centrifugal force and increases driving comfort and safety. The laws of physics specify the relationship between speed, radius, superelevation and side friction. These laws can be captured by a simple mathematical formula, which can be used for design. As a result, the maximum speed in a curve increases with superelevation (ERSO, 2006). A transition zone between the tangent and the horizontal curve is needed to gradually introduce the superelevation (the transition curve is usually used on that purpose).



Figure 3.4. *Superelevation on horizontal curves (PIARC 2003)*

Safety effects

According to the above, **increasing the radii of horizontal curves** may significantly reduce the number of accidents, especially when the initial radius of the curve is less than 2,000 m. (Elvik, Vaa, 2004). It is interesting to note that, according to Hauer (1999) a given increase of the radius has the same effect on accident occurrence whether the initial radius was 100 m or 1,000 m.

The **introduction of transition curves** (clothoides) may lead to a reduction of 10% of injury accidents.

A reduction of the proportion of road length which lies in sharp horizontal curves is also associated with important safety effect in most studies. On the other hand, **increasing the distance between horizontal curves** is not associated with positive safety effect, as curves after longer straight sections are expected to be more of a surprise to drivers (Elvik, Vaa, 2004).

Calculation of the safety effect derived from superelevation treatments has proved that this specific investment may have a lower or a higher benefit, depending on the extent of the treatment but also on other road environment conditions. Harwood et al. (2000) attempted to describe the relationship between **superelevation** rate and road accident frequency. Their analysis indicated that accident frequency was higher on highways that were deficient in the amount of superelevation provided. Superelevation deficiency is defined as the difference between the superelevation provided on the curve and that specified in the document *A Policy on Geometric Design of Highways and Streets* (AASHTO, 2004). Road accident frequency was found to be higher with increasing superelevation deficiency and more specifically, curves with a superelevation deficiency of 5% would likely experience an increase of 15% in accidents. According to another relevant study, improving the superelevation has a positive safety effect in terms of accidents reduction, which can range from 5 to 10% (Zegeer et al., 1992).

Other effects

Mobility effects may be observed following curve treatments, as travel speeds may be affected. However, such effects are not documented.

Costs and cost-benefit analysis (CBA) examples

Improving horizontal curves design is not expected to be cost-effective in most cases, due to the increased implementation costs. Elvik and Vaa (2004) emphasize that other measures, such as appropriate road marking and signals, warning the drivers on the deficiencies of a curve, are expected to be clearly cost-effective. It can be deduced that it is extremely important to adopt the design guidelines concerning horizontal curves in the planning and implementation process.

3.3.3 Vertical curvature treatment

Description

The vertical curvature of a road is an important safety factor. Accident risk is higher on **gradients** than on level sections and accident occurrence increases with gradient (Harwood et al., 2000). On sections with high gradient, safety problems may occur from speed differences between passenger cars and heavy vehicles (e.g. heavy vehicles idling on uphill sections), as well as vehicles braking on downhill sections (e.g. increases in braking distances and possibility of heavy vehicle brake overheating) On **crest curves**, sight distance may not be sufficient for safe overtaking, especially when the curve radius is low. Sight distance problems may also be encountered in **sag curves**. (ERSO, 2006).

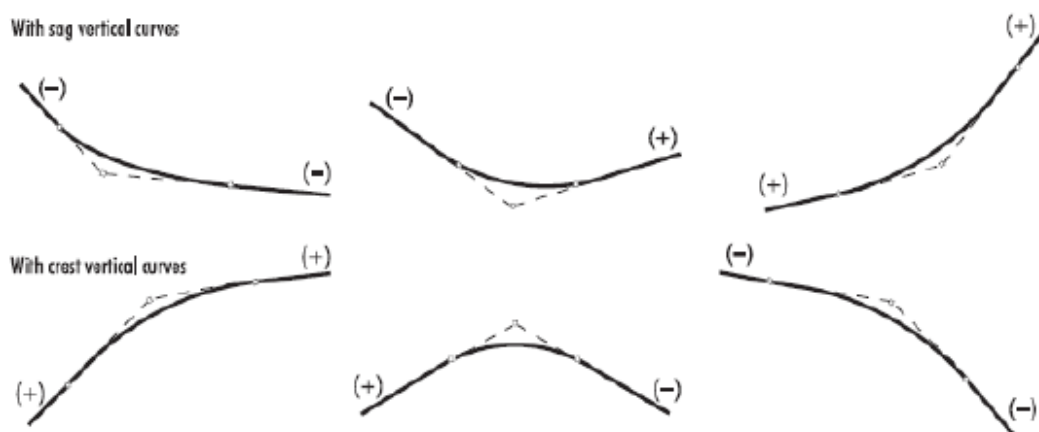


Figure 3.5. Crest and sag vertical curves (PIARC, 2003)

It is important to note that a horizontal curve radius will be perceived incorrectly if the curve overlaps with a crest or sag vertical curve (Hassan et al. 2002). In particular, the overlapping of a horizontal and a crest vertical curve may result in limited sight distance and prevent the prompt perception of the curve, whereas the overlapping of a horizontal and a sag vertical curve may create a false impression of the degree of curvature (Smith, Lamm, 1993).

Safety effect

Existing studies show that **reducing gradient** reduces the number of accidents. According to Harwood et al. (2000) in rural two-lane roads, an increase of the roadway grade by 2% leads to an increase in total road accidents of 3%, whereas a 6% increase of the grade results to a 10% increase of the overall number of accidents. In addition, Hauer (2001) cites an earlier study of Miaou, according to which decreasing the roadway grade by 1% reduces the number of road accidents by 8.1%.

Reducing the proportion of road length, which lies in sharp crest curves, is also associated with significant effect on road accidents, as drivers are more cautious when there is limited sight distance on crest curves and adapt their driving behaviour accordingly by reducing their speed. On the other hand, according to relevant studies in **sag curves** the treatments may lead to an increase in drivers speeds, compensating for the safety effect (Elvik, Vaa, 2004).

Other effects

Vertical curvature and gradient treatment may bring an important benefit in terms of mobility, through an important increase in travel speeds. As regards environmental effects, both noise and pollution effects may be expected, due to reduced variation of travel speeds.

Cost-benefit analysis (CBA)

Costs of vertical alignment treatment may vary significantly in different sites and also depends strongly on the type of treatment. As expected, treatments related to the improvement of the vertical alignment are not very cost-effective. On the other hand, improvements concerning sight clearance interventions are expected to be cost-effective. It is noted that the limited number of studies on vertical alignment treatment does not allow for safe conclusions to be drawn.

3.3.4 Cross-section treatment

Description

Sufficient width and appropriate design of a road's cross-section is important, especially on undivided roads, in order to allow for safe overtaking, to accommodate the movement of heavy vehicles and to ensure appropriate sight distances. The total width of the cross-section plays an important role in road safety (Zegeer and Council., 1995)

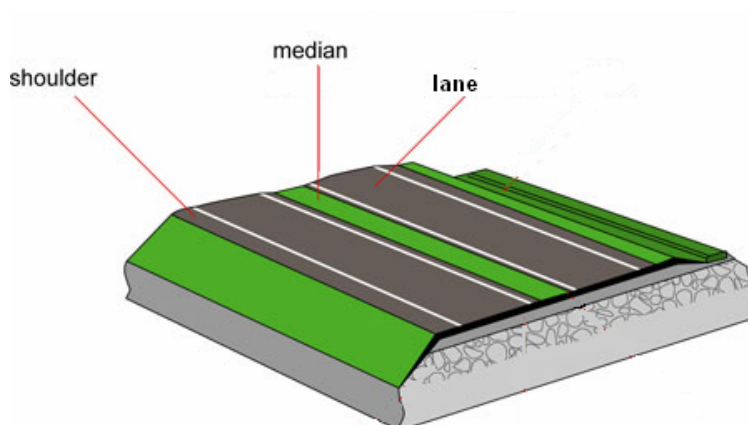


Figure 3.6. Main cross-section elements

The cross-section elements may have an important effect of accident risk on a road. For instance, **lane width** should be in accordance to the expected operational speed, as it tends to influence specific types of accidents, especially on two-lane, undivided highways. These accidents would include single-vehicle run-off-road accidents, same direction sideswipe, and multiple vehicle opposite direction accidents (Harwood et al, 2000). Increasing lane width is expected to improve road safety up to a certain degree and according to Hauer (2000b) there is little safety benefit to be obtained from widening lanes beyond 3 - 3.5 m and widening beyond 3.5 m may be even to the detriment of safety (on two-lane roads). Additionally, very large lanes may lead to increase of travel speeds with negative effects on road safety (IHT, 1990).

The implementation of **shoulders** (especially paved ones) also contributes to improved road safety of rural roads. Several studies have pointed to the fact that shoulder width is more beneficial to safety at higher traffic volumes than at lower ones. Moreover, other research studies findings indicate that for injury accidents, there is a certain shoulder width (between 1.8 and 2.5 m) above which the number of injury accidents increases, roads with paved shoulders are associated with fewer accidents than similar roads with only grass verges and also the provision of full shoulders instead of only curb-and-gutter on multi-lane suburban highways is associated with a 10% lower accident rate (Hauer, 2000c). However, very narrow shoulders (e.g. <0.5 m) or very wide emergency lanes (e.g. >3 m) may end up being used by drivers as regular lanes and result in increased number of accidents (Ogden, 1997, IHT, 1990). However, in certain cases there is an advantage in emergency lanes of about 3 metres wide, in that they can be used as traffic lanes during maintenance work using the zero-four concept. As it is the case for lane width, very large shoulder width may also have negative effect on road safety.

The introduction of a **median or central reservation**, the area which separates opposing lanes of traffic, may also have an important contribution in reducing the number of road accidents, especially on two-lane roads, and concern the head-on, opposite-direction sideswipe and run-off-road-left road accidents. Medians may vary from double white lines with hatching between them, to a clear zone transformed into a "green area", to steel or concrete barriers in the central reserve of the divided roads. However accidents still occur because of drivers crossing the median and entering the opposite traffic stream (ERSO, 2006). The total number of these accidents decreases when median width increases and the reduction can vary from 35% to 44%, depending on the type of road (rural/urban freeway/non-freeway) (Hadi et al., 1995). The larger the width of the median, and also possibly the larger the width of the initial (previous) type of separation, the better the road safety is (Knuiman et al.1993, Hauer, 2000a).

Two plus one (2+1) roads are three lane undivided roads, whose section has a middle lane changing direction every 1 - 2.5 kilometre. The construction method can be applied to new road sections as well, but since the upgrading is a low-cost measure compared to, for instance, construction of a new motorway, the standard application is on existing road sections. In principle, the 2+1 road construction takes place on 13-meter-wide roads, and it is considered as means of upgrading other solutions, mainly wide shoulders or wide lanes. Figure 3.7 (ROSEBUD, 2005) illustrates the principle difference between these three approaches. Between the three different approaches, the distinctive advantage of the 2+1 solution is that it prevents head-on collisions, whereas wide shoulders and wide lanes allow for greater driving margins and can reduce run-off-road accidents.

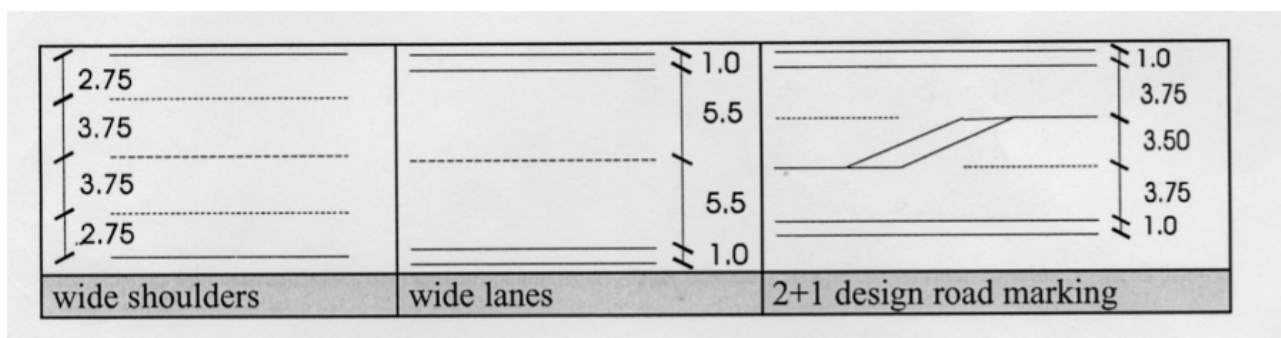


Figure 3.7. Main cross-section elements

Safety effect

Elvik and Vaa (2004) summarise the findings of several existing studies on cross-section treatments, as follows: **increasing the number of traffic lanes** should be primarily seen as a measure to increase road capacity, as in some extreme cases of very low volume and consequently high speeds it may lead to higher accident rates. However, there are other cases, such as the increase from 4 to 6 traffic lanes on roads in urban or rural areas, where all injury road accidents decrease by 11% and 32% respectively. Additionally, an increase in the number of traffic lanes from 2 to 3 on roads in urban areas may result to a 12% reduction on the total number of road accidents. A small or medium **increase of the total cross-section width** (e.g. by 1-3 metres) is expected to lead to a reduction of accidents; the same stands for respective increases of lane and shoulder width. The **introduction of a median**, as well as the **increase of a median's width**, is generally associated with a reduction of accidents, however the extent is not always evident. It should also be noted that the population density of the area around the examined road sections, as well as the traffic volume, are important for the calculation of the safety effects deriving from cross-section treatments.

As regards **2+1 roads**, the most effective crash reduction will result from the reduction in head-on collisions. The safety effect is further increased in the case of physical instead of painted) separation between traffic streams (e.g. cable barrier separation) (Bergh et al., 2005).

Other effects

Cross-section treatments have an important effect on the capacity of the road, improving mobility. The environmental disturbances are not expected to be significant, unless a large increase of the cross-section width takes place.

Cost-benefit analysis (CBA) examples

The costs of cross-section elements treatment may vary significantly in different sites and also depends strongly on the type of treatment. Usually such treatments are not cost-effective, as the increased implementation costs can not be compensated by the safety and mobility benefits, mainly due to the fact that certain parts of the road network in many countries are very old and poorly maintained by the appropriate authorities

- Cost-effectiveness results for 2+1 roads were estimated in Finland and Sweden at 1.25:1 to 2.25:1 (ROSEBUD, 2005), indicating that positive results can also be achieved, even though in Finland and Sweden very low traffic densities are recorded.

3.3.5 Roadside treatment

Description

The **roadside** is defined as the area between the outside shoulder edge and the right-of-way limits (AASHTO, 2002) and is an important road element, affecting both accident occurrence and severity. An appropriate roadside configuration may not only reduce the probability of an accident, due to improved visibility, but may also reduce the consequences of an accident, due to elimination of obstacles and absence of steep slopes. Consequently, the roadside area is a primary component in the creation of a forgiving road environment. The establishment of forgiving roadsides is one of the highest short-term priorities of Road Directors in Europe (CEDR, 2006).

Roadside treatments mainly include flattening of **side slopes**, creation or extension of **clear zones**, the introduction of appropriate marking and signalisation and removal or securing of roadside hazards. Moreover, **safety barriers** are often used, to prevent the collision with obstacles along the roadside, in cases where the obstacles themselves (e.g. trees) cannot be removed.

The clear zone is defined by the AASHTO Roadside Design Guide as the total roadside border area, starting at the edge of the travelled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. It is generally accepted that a wider clear zone creates a safer environment for potentially errant vehicles.

Safety barriers are longitudinal barriers used to shield motorists from natural or man-made obstacles located along either side of road. The implementation of safety barriers can take place along the embankments and can include replacement of existing safety barriers by softer ones, installation of median safety barriers on divided highways or safety barriers between the lanes of opposing traffic on undivided highways.

Safety effects

The higher the roadside clear zone is, the higher is the probability than the accident will be avoided (PIARC, 2003). Zegeer et al. (1988) estimated the effects of **clear zone widening** on two-lane rural roads, and calculated the expected percentage reduction of “related accidents” (the total of run-off-road, head-on, and sideswipe accidents), ranging from 13% reduction for a 1.5m increase of the roadside clear recovery distance to 44% corresponding to a 6.2m increase.

Moreover, **flattening side slopes** reduces the probability of rollover in run-off -road accidents and obstacle-free zones improve visibility and reduce the probability of collision with a fixed object (obstacle) in run-off-road accidents. Both treatments are associated with significant safety effects (Graham, Harwood, 1982, Zegeer et al., 1988). Neuman et al. (2003) report that rollover rates are significantly higher on slopes of 1:4 or steeper, comparing to slopes of 1:5 or flatter and is concluded that single-vehicle run-off-road accidents (which include, but are not limited to rollovers) can be significantly reduced by flattening existing side slopes to 1:4 or flatter and the corresponding decrease in total road accidents can be estimated in around 15%. Allaire et al. (1996) evaluated side slope flattening projects and run-off-road collision frequency and severity using a before-after study of 60 projects that involved side slope flattening for at least some portion of the project. They found a statistically significant benefit for slope flattening, as the reduction in run-off-road collision rates varied by comparison and by injury severity group from 3% -50%.

As regards **safety barriers**, changing to safety barriers that meet the EN 1317 standard has a damage-reducing effect, but this is smaller than the effect of setting up safety barriers in places where previously there were none. Additionally, safety barriers do not have an equally positive effect on all types of obstacles, as a significant reduction in the severity of injuries sustained in collisions with trees, rock faces and driving off the road in steep slopes is observed. The reduction in injuries is, however, smaller with regard to hitting signposts or ditches. In general, safety barriers appear to have an important safety effect of around 45% reduction in fatalities and injuries (Elvik, Vaa, 2004).

Other effects

The improved visibility may also lead to increased travel speeds, improving thus mobility. The environmental aspect may be more or less important, depending on the extent of the obstacle-free zone.

Cost-benefit analysis (CBA) examples

The costs of improving roadsides vary among countries and sites and no general rule can be deduced. For instance, flattening side slopes can be more or less expensive according to the landscape. In general, though, flattening side slopes and the establishment of clear zones have a higher implementation cost than implementing safety barriers or replacing existing safety barriers to meet the EN 1317 standard. Only a few specific studies on cost-effectiveness of such treatments are available, as seen below.

- In a cost-effectiveness evaluation of safety barriers implemented along the roadside in the rural road network of the "Landes" forest in France, to prevent collisions with trees, an impressive benefit to cost ratio of 8.7:1 was estimated (ROSEBUD, 2005).
- Within the VESIPO project (2002), the implementation of roadside safety barriers on rural roads in Switzerland resulted in a benefit to cost ratio of 32:1.
- Elvik and Vaa (2004) report a Norwegian experience, according to which roadside safety barriers are cost-effective only on roads with an Average Annual Daily Traffic higher than 3,000, which however, cannot be considered as representative for all European countries due to different traffic volumes and population density.

3.3.6 Roadway Traffic Control and Operational Elements

Description

Roadway traffic control and operational elements concern several road investments, which can improve the safety level of a road section. They include signs, delineation, pavement markings and markers, rumble strips etc.

Traffic signs are typically classified as one of three categories: regulatory signs, warning signs and guide signs. As defined in the "Convention on road signs and signal report" developed by the UNECE (UNECE, 1968), but also in the "Manual on Uniform Traffic Control Devices" (Federal Highway Administration, 2003), regulatory signs provide notice of traffic laws or regulations, warning signs give notice of a situation that might not be readily apparent, and guide signs show route designations, destinations, directions, distances, services, points of interest, and other geographical, recreational or cultural information.

Signage treatments (excluding VMS and signs at junctions, which are separately analysed) may concern existing signs corrections, installation of active Close-Following Warning signs, Limited Sight Distance (LSD) warning signs or static warning signs (Advance Curve Warning and Recommended Curve Speed) at Horizontal Curves.

Delineation and pavement markers and markings have long been considered as essential elements for providing effective guidance to drivers. They refer to any methods of defining the roadway operating area for drivers and may include delineation devices such as pavement markings made from a variety of marking materials, raised pavement markers, pavement markers, and post-mounted delineators.

Rumble strips are road safety features used to alert road users straying off the road or drifting into the opposing lane of traffic both by causing a vibro-tactile and an audible warning. They are intended to reduce road accidents caused by drowsy or inattentive motorists and can be distinguished in shoulder, centreline or transverse rumble strips. Rumble strips also help reduce highway hypnosis—a condition where white lines and yellow stripes on long, monotonous stretches of straight freeway can mesmerise and wreak havoc with a driver's concentration. In the relevant literature several concerns have been identified with the use of rumble strips regarding noise generation affecting surrounding residents, bicyclists and motorcyclists opposition, improper driver reaction and accident migration. However their advantages are generally accepted to outweigh the disadvantages (Griffith, 1999). Rumble strip installation costs are low and require little or no maintenance. There is no noticeable degradation of pavement due to rumble strips and additionally, they are effective in snow and icy conditions and may act as a guide in inclement weather for truck drivers.

Safety effects

Elvik and Vaa (2004) reviewed a previous study by Lyles et al., finding that adjustments and **improvements to existing signs**, according to certain standards, seem to reduce the number of injury and damage-only accidents and more specifically when applied on local streets result to a 15% decrease in injury accidents, and a 7% decrease in damage-only accidents. However, the implementation of warning signs for reducing speeds at horizontal curves have generally proved ineffective by several studies, for example Fitzpatrick et al. (2000), as opposed to the installation of a fixed radar, which can result to significant speed reduction.

Evaluation of the effectiveness of implementing post-mounted **delineators'** on sharp curves by Neuman et al. (2003) showed a reduction of the run-off-road accidents by 15%. However, a recent review by Forbes (2003) of a previous study shows that the implementation of post-mounted delineators, chevrons and raised pavement markers on horizontal curves resulted in increased night-time driving speeds. These results seem to be similar to the findings from another recent study by Bahar et al. (2004) that examined the safety effects of delineators at horizontal curves and concluded that drivers tend not to reduce their speed in poor visibility conditions and for roadway segments with lower geometric standards. Additionally, the implementation of such treatments caused drivers to move away from the delineation measures when driving at night or under poor visibility conditions. For example, in the case of centreline **raised pavement markers**, drivers will move away from the centreline toward the shoulder. While this behaviour may reduce the incidence of head-on collisions, it may increase run-off road collisions, especially on roads with lower design standards (i.e., with narrow and/or gravel shoulders).

In the same study, the safety effect of **chevrons** was investigated and was shown that chevrons can be seen considerably further than raised pavement markers because of their orientation. Studies of the relationship between speed in curves and curve geometry show that curve radius and curve angle are important predictors of speed and studies of driver response show that drivers viewing images of curves (i.e. equivalent to unfamiliar drivers with no experience of the curve) indicate that the deflection angle curve is more important than the radius in determining approach speed. For these reasons, chevron markers which delineate the entire curve angle are generally recommended on sharp curves, even though their safety effect is not really significant. They are considered to be more effective because of their greater size and the placement above the road surface makes them considerably more visible, even though their effects on lateral placement, speed and speed variance are modest.

An overall conclusion from the relevant studies that evaluate the safety effect of **rumble strips** is that they can be very effective in the reduction of accidents of a certain type, such as skidding or run-off accidents in curves or accidents that are the result of failing to obey the traffic control device or failing to adapt to new conditions at the specific location. However, quantitative results are not always available as it is difficult to be isolated from other road safety elements. Usually, a combination of traffic control and operational elements is implemented at selected road sections. A relevant study undertaken in the State of Pennsylvania revealed that the application of rumble strips in 53 road segments totalling 560 km of roadway resulted to a reduction of 60% in treatable accidents, or a decline in rate by 1.43 per 100 million vehicle kilometres (Hickey, 1997).

3.3.7 Speed limits/reduction of operating speed

Description

In practice, there are major differences in the speed at which different drivers drive given the same external conditions. Moreover, many drivers have an unrealistic expectation of being able to control their vehicle at much higher speeds than the posted speed limit (Elvik and Vaa, 2004).

Speed management includes a broad range of planning, engineering and interventions actions aiming to control and enforce vehicle travel speeds, reduce excess or inappropriate speed and ensure safer travel conditions for all road users. This issue is a top priority for 34% of the countries, and for 35% of the countries it is of medium priority (CEDR, 2006).

The most appropriate combination of measures will differ with circumstances. In principle, effective speed management requires an integrated, systematic and stepwise approach. Within the current system of fixed **speed limits**, the following steps are important (ERSO, 2006):

- **Setting speed limits:** The basis for any speed management policy is setting speed limits. Speed limits need to reflect the safe speed on that particular road, related to road function, traffic composition, and road design characteristics. Furthermore, speed limits need to be credible, i.e. they must be logical in the light of the characteristics of the road and the road environment.
- **Information about the speed limit:** The driver must know, always and everywhere, what the speed limit is. The conventional way is to use consistent roadside signing and road markings. In-vehicle systems to inform drivers about the speed limit in force are likely to be introduced progressively.

- **Road engineering measures:** At particular locations low speeds may be crucial for safety (perceived or actual). Examples are near schools or homes for the elderly, at pedestrian crossings, at intersections. At these locations, physical speed reducing measures such as speed humps, road narrowing and roundabouts can help to ensure cars maintain a safe speed.
- **Police enforcement** to control the intentional speeder: If the three previous actions are applied, it can be assumed that the unintentional speed violations are an exception. Drivers who still exceed the speed limit do so intentionally. Police enforcement will remain necessary to control and punish that group of drivers.

Several actions and measures included in the above framework are analysed in other sections of this document (see section 3.2.6 - Traffic control and operational elements, section 3.2.8 - e-safety systems and section 3.4.1 - Traffic calming). This section analyses one of the main tools of speed management concerning speed limits.

Speed limits aim at setting a compromise between the mobility needs of drivers and the safety and environmental needs for all users of the road infrastructure. A speed limit must reflect the function and quality of the road to ensure a safe speed limit. In addition, a speed limit should be supported by (changes in) the characteristics of the road and the road environment in order to be credible for the road user (ERSO, 2006). Moreover, the speed limits used by different countries in different types of roads may vary considerably (Vis and Van Gent, 2007). However, the de-facto standard in the EU is 80, 90 or 100 km/h in rural roads, 50km/h in urban areas, 30km/h in residential areas and 120km/h or 130km/h on motorways (CEDR, 2006).

Interventions concerning speed limits can be of three types (Elvik and Vaa, 2004, Cohen et al. 1998)):

- raising existing speed limits
- changing from unrestricted speed limit to speed limit
- lowering existing speed limit

Complementary measures, like **speed transition zones**, help to indicate the transition from one traffic environment to another, from one traffic behaviour to another, and primarily to another speed (Herrsted et al. 1993). When entering the lower speed zone, in particular after a period of driving at a high speed (e.g. in the entrance of a village from a major through road), drivers will easily underestimate their travel speed, and hence insufficiently adapt their speed (ERSO, 2006). The first principle is that complementary measures along the through route within the urban area are required. The second principle is that measures at the transition zone should be such that they achieve a cumulative effect, culminating at the actual gateway to the towns or villages. The latter can be achieved by a combination of road narrowing and the introduction of vertical elements, culminating in the gateway (ETSC, 1995).

It must be emphasised that Police Enforcement is an integral part of any speed limit policy. Installation of speed limit signs, or changes in existing speed limits without adequate police enforcement, might not lead to the expected effect.

Information on the safety effects on information about the speed limit can be found in sections 3.2.6 - Traffic control and operational elements and 3.2.8 - e-safety systems. Information on the safety effect of engineering measures to support speed management can be found in sections 3.2.6 - Traffic control and operational elements and 3.4.1 - Traffic calming.

Safety effect

Changes from **unrestricted speed to the use of speed limits** have led to reductions in the number of accidents at all levels of severity. In particular statistically significant results of meta-analysis reported by Elvik and Vaa (2004) indicate that:

- In all speed limit reductions, fatal accidents are reduced by 11-13% and all accidents with casualties are reduced by 13% on average.
- In reduction from unrestricted speed limit to speed limit over 100 km/h, fatal accidents are reduced by 11% and all accidents with casualties are reduced by 16%
- In reduction from unrestricted speed limit to speed limit of 80-97 km/h, fatal accidents are reduced by 19% and all accidents with casualties are reduced by 22%

It can be deduced that the lower the speed limit set, the higher the safety benefit.

Lowering existing speed limits has been associated with impressive safety benefits. In particular (Elvik and Vaa, 2004):

- Lowering speed limit from 130 to 120 km/h, from 130 to 110 km/h and from 120 to 110 km/h results in 11% decrease of all accidents. No respective reduction as regards fatalities is expected, though.
- Lowering speed limit from 115 or 100 km/h to around 90 km/h (88-97) results in 9% decrease of all accidents and up to 55% reduction of fatal accidents.
- Lowering any speed limit lower than 100 km/h (i.e. 90-80) by 15% on average is associated with important safety effects for all accidents. It is interesting to note that in this case the reduction of fatal accidents is consistently almost twice the reduction in all injury accidents.

Speed transition zones may also bear important safety benefits. Taylor and Wheeler (2000) evaluated the effects of 56 traffic-calming schemes in British villages on main interurban roads where the speed on the approach to the villages was typically 90 km/h. It was found that schemes with only gateway measures resulted in a reduction in fatal and serious accidents within the villages of 43%. The number of minor injury accidents also increased by 5%. Higher accident reduction rates were reported for schemes with additional measures inside the villages (road narrowing, mini-roundabouts, speed humps), where the number of fatal and serious accidents decreased by about 70% and the number of minor injuries by about 37% (ERSO, 2006).

Other effects

Reducing speed limits reduces mobility, as travel time increases. On the other hand, more equal distribution of travel speed may theoretically increase the capacity of the road infrastructure. Moreover, reducing speed limits and consequently travel speed is expected to bring environmental benefits, both in terms of noise and emissions.

Costs

The costs of speed management and speed limit related measures are relatively low, especially when this is carried out by means of traffic signs. Additional road engineering measures (e.g. speed humps) are also of relatively low cost in relation to other infrastructure treatments. These costs may increase significantly when Intelligent Transport Systems applications are used for setting and enforcing speed limits.

3.3.8 e-Safety Systems

Description

e-Safety concerns a set of systems aiming to improve road safety by using new information and communications technologies, namely applications of **Intelligent Transport Systems (ITS)** (European Commission, 2002), by reducing or eliminating human and road environment risk factors. e-safety systems have the potential to improve road safety by influencing traffic exposure, by reducing the probability of crashes and by reducing injury consequences. More precisely, driver assistance systems support the modification of the driving task by providing information, advice, and assistance and they influence directly and indirectly the behaviour of users (Golias et al., 2002).

There are already a number of well known and widely implemented systems which help the driver to maintain control of the vehicle even when he has exceeded its 'normal' limits of handling (e.g. ABS, ESP, Lane Support Systems, Safe Following Systems). In addition to these, a new generation of active safety systems and Advanced Driver Assistance Systems (ADAS) has emerged. These systems take into account not just the driver and the vehicle, but also the environment around the vehicle. In this section, the analysis focuses on the infrastructure and the driver - infrastructure interaction risk factors, which can be addressed by means of e-safety systems. Accordingly, applications requiring some involvement or actions on the part of road network managers are also included in the presentation.

In particular, the most important infrastructure and environmental factors that may have an impact on road safety are road geometry, pavement conditions, weather conditions and road lighting conditions (Spyropoulou et al., 2007). e-Safety systems that reduce road accidents caused by the interaction of the driver with the road environment, mainly aim at changing driver behaviour in relation to traffic rules or when driving under hazardous conditions, by raising driver awareness on these rules and conditions, with the employment of systems that inform or warn the driver. The main systems that fall within this category are briefly described below:

The classic systems for driver information are those related to **navigation routing**, which provide location and route guidance input to the driver. Utilising existing technology such as **Radio Data System (RDS), Traffic Message Channels and Mobile Phones**, these systems combine static information, from data sources such as compact discs or DVDs, with limited information pertaining to the traffic, weather or safety conditions along the vehicle route.

Real time traffic and traveller information systems combine the information available to users of traditional navigation systems with real time travel-related information, which they receive from the infrastructure (e.g. through dedicated radio channels, roadside beacons or wide-area transmissions). **Variable message signs (VMS)** are traffic signs on which the message given can be displayed or altered as required. Consequently, by using VMS, the total number of traffic signs can be reduced, and the sign messages can be more easily changed.

A distinction can be made between individual and collective information VMS. Individual signs provide information to an individual about his behaviour (i.e. the individual exceeds the speed limit) and collective signs provide information addressed to all road users (i.e. information about estimated travel time or congestion).

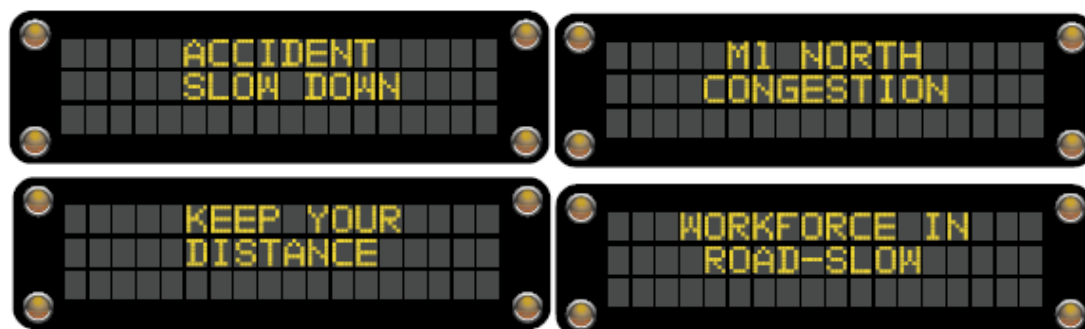


Figure 3.8. Examples of collective information VMS

Vision Enhancement Systems (VES) (CRA, 1998, Golias et al. 2002) are systems aiming at improving visibility in the driving scene under low visibility conditions (night or fog) by presenting additional visual information, using technology ranging from specially designed headlights to infrared and radar sensors, through an in-vehicle screen display.

A promising category of e-safety driver information systems refers to systems collecting and analysing information on the **road surface conditions** using vehicle-mounted or fixed infrastructure road sensors (Golias et al. 2002). The collected information can then be transmitted to the in-vehicle system, where it is further processed. If unsafe road surface conditions are identified ahead of the vehicle, then the driver can be notified via audio or visual message. Furthermore, the information can be transmitted to the appropriate traffic information centres, from where it can be disseminated to other road users as well as the appropriate authorities.

Cooperative ITS (Tsugawa et al., 2000) are based on the coordination of data received from various different actors (the vehicle of the user, other vehicles, road environment (traffic lights) etc.) and may comprise potential future solutions targeting at risk factors related to traffic violations. Until today, however, these have not been developed at a sufficient level (Spyropoulou et al. 2007).

Finally, with respect to post-crash functions, the most popular such system is the **emergency-call (e-Call)**. Once the accident has occurred, the emergency services are alerted automatically or manually and the necessary data including the exact position of the accident, the driver and accident characteristics is transmitted. The European e-Call initiative is set to be launched in 2009 offering a common telephone number (112) at which the call will be made (European Commission, 2005).

Safety effects

The procedure of application and evaluation of e-safety systems seems to be a rather slow one. The quantification of the impact of such systems on accident rates can only be established after they have been implemented for a long period so that specific elements including technological features, penetration rates and driver behaviour when using the systems have been stabilised. Still, specific elements of their impact can be estimated indirectly in some cases (Spyropoulou et al., 2007).

In general, the criteria used for the assessment of the safety effect of e-safety systems can be summarised as follows (Golias et al., 2002):

- Avoidance of inappropriate speed
- Keeping appropriate longitudinal and lateral distances
- Support of driver awareness

Classical **navigation systems** do not incorporate real-time information, but instead are limited to using historical traffic information; therefore, they are not expected to provide directly significant safety benefits (Golias et al., 2002).

On the contrary **real time traffic and traveller information systems** are associated with important safety benefits. Collective information **VMS** are associated with important safety effects in most cases. However, Elvik and Vaa (2004) underline that some of the available results should be considered with caution. The highest safety effects of VMS correspond to accident or weather conditions (e.g. fog) warnings (ranging from 45-85% accidents reduction), but certainly this applies more in the Northern European countries, where the adverse weather conditions affect more road safety. On the other hand, queue or congestion warnings on motorways are associated with less impressive safety effects; in particular, while injury accidents appear to slightly decrease, material damage only accidents tend to increase. It can be deduced that VMS providing information on queues lead to frequent lane changes from drivers aiming to avoid the queues or seeking for an exit, and this behaviour may increase the probability of accident occurrence. No statistically significant results of the safety effect of individual information VMS are available.

Vision enhancement systems are expected to improve road safety, as they will allow drivers to 'see' objects (or pedestrians) on the road that are not visible by head lamps at night or in poor visibility conditions, by transmitting their image via an in-vehicle screen display (Stahl et al., 1995). However, no validated quantitative results are available. Although no quantitative results are available, **state of the road surface systems** are expected to have significant safety effects, as drivers' awareness of the road surface conditions can have considerable positive impacts on both safety (as a combination of appropriate driving speed adoption, appropriate headway adoption, and increased driver awareness) as well as traffic efficiency, through better driving behaviour in relation to speed (Golias et al., 2002).

A Finnish in-depth accident study of the effect of **e-Call** indicated a potential reduction of fatalities of around 5% due to more efficient incident management (Virtanen, 2005).

It is noted that behavioural adaptation of users when using such systems is feared, as drivers may feel safer and employ higher driving speeds. Concerns including drivers dividing their attention between the external and internal environment have also been raised (CRA, 1998, Golias et al. 2002).

Other effects

Some e-Safety systems (e.g. VMS) displaying information on speed warnings (i.e. individual ones) or weather warnings (i.e. collective ones) are expected to reduce mobility, by reducing travel speeds. This reduction of speed may also affect noise and emissions; however, there are currently no studies quantifying these environmental effects.

Costs

Some e-Safety systems are more expensive than ordinary traffic safety systems, as their implementation includes not only mechanical and electrical equipment, but also traffic detection equipment and their operation and update requires a traffic control centre. Moreover, in the case of variable message signs, their maintenance is rather costly.

Cost-benefit analysis (CBA) examples

In general, due to the increased safety effect, VMS are expected to be (marginally) cost-effective, especially those corresponding to accident / incident or weather warnings. No CBA results are available for the other e-Safety systems related to the infrastructure or the driver - infrastructure interaction.

3.2.9 Road surface treatment

Description

Road surface treatment may concern ordinary resurfacing (e.g. within the framework of essential maintenance) or special changes to road surfaces (e.g. bright road surfaces, high-friction road surfaces etc.), in order to prevent dangerous unevenness or damage on the road surface, to reduce vehicle wear and tear and to increase driving comfort and safety.

Resurfacing concerns the normal replacement of existing road surface with a new road surface. Improving the **evenness** of a road surface involves filling potholes, sealing cracks and in general repairing any damage that has resulted in uneven road surface and may cause drivers to lose control of their vehicle. Improving the **friction** of the road surface may involve laying a high-friction (porous asphalt) surface or sinking grooves in the road surface, in order to ensure sufficient drainage. Improving **brightness** of the road surface involves using brighter asphalt, in order to improve sight conditions for drivers.

Safety effects

Ordinary **resurfacing** does not appear to reduce the number of accidents; on the contrary, there is a tendency towards accidents increase. It is possible that drivers compensate for the improved road surface effect by increasing their travel speeds. Hauer et al. (1994) concluded that in projects involving resurfacing only, safety is initially reduced, while in projects involving re-surfacing and other roadway improvements, it may be improved, and they also concluded that within the first 6-7 years of pavement life, safety improves as the pavement ages. However, a more recent study aimed at assessing the safety impact of re-surfacing, with or without additional action, was unable to reach clear conclusions on the subject and recommends additional research (Hughes et al., 2001).

For the same reason (i.e. increased travel speed), improving road surface **evenness** appear to have negative safety effect. On the contrary, a positive safety effect is associated with road surface **friction** improvements; the lower the initial road surface friction, the more important the safety effect. However, this effect exclusively refers to accidents occurring on wet surface conditions (Elvik, Vaa, 2004, PIARC, 2003), whereas accidents on dry surface conditions do not appear to be affected.

Moreover, from the very few studies available, improving road surface **brightness** does not appear to affect the number of accidents.

Other effects

Road surface treatments are expected to improve mobility, as travel speeds will increase due to improved driving comfort. The speed increase depends on the traffic volume and on the extent of the treatments.

An environmental benefit in terms of noise reduction should be expected, as a result of a new or improved road surface of appropriate thickness. However, this is a short-term effect that shall disappear shortly after the treatments are implemented (e.g. after the first winter).

Costs

The costs of road surface treatments depend on the type of treatment (e.g. porous asphalt is more expensive) and the expected lifetime of the road surface.

Cost-benefit analysis (CBA) examples

Road surface treatments are generally expected to be cost-effective, especially in high-traffic roads. The results, however, depend on the type of treatment. Ordinary re-surfacing and improvements in road friction are generally cost-effective in high-traffic roads, whereas in low-traffic roads the benefits appear to be roughly equal to the costs. It is noted, however, that the increased benefits are mainly due to mobility effects and not to safety effects.

3.3.10 Lighting treatment

Description

Sufficient **road lighting** may reduce the number of accidents in the dark by making it easier to see the road, other vehicles and the surroundings of the road. It is important to provide uniform lighting of the entire carriageway; therefore lighting should be also selected according to the reflective properties of the pavement. Lighting implementation is necessary according to priority at junction areas, on roads around or approaching inhabited areas, and on roads with high traffic volumes and / or operating speeds (ERSO, 2006).

Safety effects

Several studies have demonstrated that the implementation of sufficient **artificial lighting** can significantly reduce the number of accidents in the dark, even though in certain cases the travel speed significantly increases. It is noted, though, that this effect is more important for accidents involving pedestrians than on other accidents. Moreover, the effect of road lighting does not vary significantly among different road environments (motorways, urban and rural areas). **Improving existing lighting** also has a significant safety effect in most studies (Elvik, Vaa, 2004).

It is noted though that the effects may be somewhat different when the measures are applied in different areas or conditions (e.g. road sections or junctions).

Other effects

No studies exist on the effects of road lighting on mobility or on the environment. Some increase in traffic volumes in the dark may be observed. The main weakness of lighting treatments is the operational costs and the waste of energy, which has well-known negative environmental effects. In particular, the continuously increasing lighting of the road networks in Europe within the last years, resulting to a significant waste of energy and financial resources might put an end to the artificial lighting of roads in rural areas or motorways. Such recent example can be found in Belgian Wallonia, where all motorways were initially lighted and it was decided to stop lighting them due to high energy costs.

Cost-benefit analysis (CBA) examples

The costs of road lighting vary very much in relation to the type of installation implemented. Because of the important safety effect and the relatively low cost, compared to other infrastructure treatments, installing or improving road lighting is expected to be cost-effective. An exception may concern rural roads of very low traffic (Elvik, Vaa, 2004).

- Implementation of road lighting in Norway was found to be highly cost-effective with a benefit to cost ratio of 7:1 to 9:1 (PROMISING, 2001). Upgrading existing lighting appears to be of somewhat less, but still satisfactory cost-effectiveness (2.5:1 to 4:1) (Elvik, Vaa, 2004).

3.3.11 Rail/road crossings treatment

Description

Rail/road crossings treatments are intended to reduce the probability of accident occurrence between trains and other road users, by either removing level crossings or equipping them with warning signals and barriers (Elvik, Vaa, 2004).

Rail/road grade crossings are intended to eliminate the probability of accident occurrence, through the full separation of the crossing movements.

Another option is the **protection of level crossings**, by means of traffic signs or automatic barriers usually combined with flashing signals and sound. The success of this type of treatment also depends on the compliance of the road users to the equipment; it has been found that long waiting times from the signal to the arrival of the train may reduce drivers' compliance to the crossing ban.

Safety effects

Rail/road **grade crossings** are associated with high safety effect, since the number of conflicts between different crossing movements is eliminated, resulting in zero accidents after the crossing.

Protection of level rail/road crossings are also associated with positive safety effects. The magnitude of the effect depends on the type of equipment implemented, as well as on the extent of the upgrade i.e. the equipment used before the treatment. In particular, the more extensive the treatment is, the higher the safety effect. Implementation of traffic signs warning of the level crossing may result in around 25% accidents reduction, whereas automatic barriers with light and sound signals may result in 45-65% accidents reduction.

Other effects

Rail/road level crossings treatments result in increased waiting times for road users; however, only a (small) proportion of road users shall be affected, depending on the train frequency and the vehicles traffic volumes. Some increase in noise and emissions may be observed due to the stopping and restarting of vehicles; however, there are no studies quantifying such effects. Additionally, in some countries the comfort and safety of travel are also considered by the decision makers, even though these cannot

Costs

Rail/road grade crossings are far more expensive than protection of level crossings. The cost of level rail / road crossing treatments depends on the site conditions and the type of treatment.

Cost-benefit analysis (CBA) examples

The investment is generally expected to be cost-effective. Several examples, especially from populated areas in Europe, indicate that rail/road crossing treatments are very effective. The decision though to choose between a grade or a level crossing significantly depends on certain conditions. The daily number of trains and daily road traffic volume are the main crossing parameters that need to be considered, as they influence both the accident frequencies and the extent of traffic delays, at the crossing. In some cases, conditions caused by weather or visibility consideration can also develop a need to construct the level-crossing, even if it appears to be economically disadvantageous. However, no general conclusions can be drawn.

- Rail / road grade crossings were evaluated within the ROSEBUD project (2005). Results from Finland indicated marginal cost-effectiveness; however, a satisfactory benefit to cost ratio of 1:1 to 3:1 was estimated for Israel.

3.4 Junctions

3.4.1 Effect of junction type on road safety

The choice of junction design depends upon several factors, whose relative importance varies between cases and should be assessed. These factors mainly include (PIARC, 2003, ERSO, 2006) traffic safety, road type and function, number of concurring legs, traffic volume, design and operating speed, priority setting, available room, adjacent land use, network design consistency, environmental factors and cost.

The type of junction has to be suited to the road type, the environment and capacity, in order to maintain good readability both of the road and of the junction, as well as a satisfactory level of safety. According to the above, for example, junctions or roundabouts should not be used on motorways, and signalised junctions should not to be used on rural roads, except in very special cases. The following Figure 3.9 shows guidelines for the selection of junction type according to traffic flows.

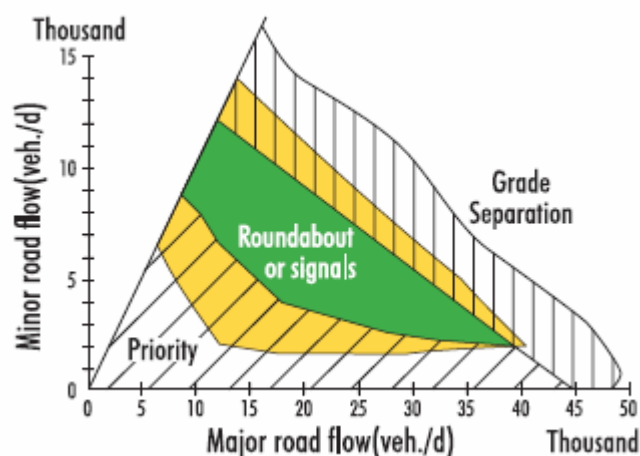


Figure 3.9. Type of junction based on traffic flows (IHT, 1987)

In the following sections, a detailed presentation of the efficiency of the different junction types is carried out.

3.4.2 Roundabouts

Description

Roundabouts are junctions with counter-clockwise (in right-driving countries) circulatory traffic (Elvik, Vaa, 2004). Persaud et al. (2001) suggest that converting conventional junctions with 'stop' signs or traffic signals to roundabouts can produce substantial reductions in motor vehicle accidents and particularly injury accidents, as roundabouts can improve traffic flow and road safety, through a reduction of the traffic speeds, but also through the elimination or reduction of specific types of conflict points that typically occur at angular intersections (see Figure 3.10). The conflicts include left-turns against oncoming or opposing traffic, rear end accidents, and right-angle conflicts at both traffic signals and stop signs. The specific configuration of roundabouts allow all traffic to come from one direction and uniform yielding rules (e.g. give way to users already in the roundabout). Left turns in front of oncoming traffic are eliminated and travel speeds are reduced.

Safety effects

An important safety effect is associated with the **development of roundabouts** (Elvik and Vaa, 2004; Brenac, 1994; Persaud et al. 2001). According to these studies, in general, the development of roundabouts resulted in substantial reductions to injury road accidents, ranging from around 20% to around 80%. In some studies, negative safety effect of roundabouts on material damage accidents was found. Moreover, roundabouts appear to have lower safety effect when replacing traffic-signal controlled junctions, than when replacing yield controlled junctions.

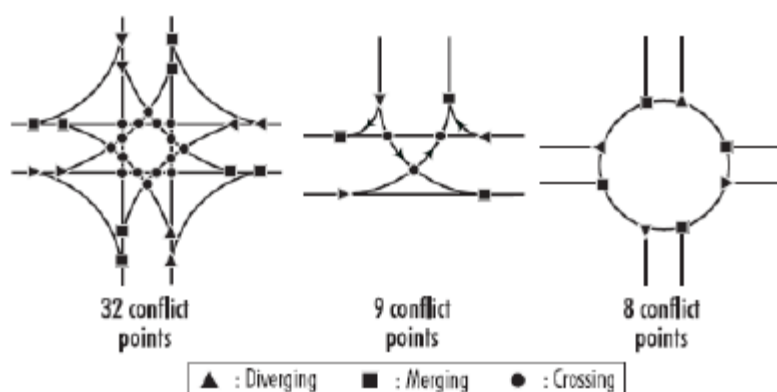


Figure 3.10. Conflict points of various junction types

Other effects

Despite the fact that roundabouts are characterised by lower travel speeds, drivers experience reduced waiting times in roundabouts, mainly due to the fact that they tend to accept smaller traffic gaps when crossing the roundabout. The overall improvement in mobility depends on the distribution of vehicles arrivals and the daily variations in traffic conditions; it is therefore difficult to establish a general rule. Concerning emissions, a reduction may be expected when replacing traffic-signal controlled junctions by roundabouts, and an increase when replacing yield-controlled junction by roundabouts. No general conclusion can be drawn on this issue.

Costs

The costs of constructing a roundabout may vary by country or site, as well as in relation to the type of roundabout.

Cost-benefit analysis (CBA) examples

In most relevant studies, roundabouts appear to be cost-effective, as a result of their important safety and mobility benefits, together with a relatively low (compared to other infrastructure) implementation cost. However, the efficiency also depends on the type of roundabout and the amount of traffic accommodated by the roundabout.

- Cost-effectiveness of roundabouts in urban areas is generally associated with benefit to cost ratios ranging from 1.25:1 to 8:1. These results are based on examples from the Czech Republic (ROSEBUD, 2005) and Norway (PROMISING, 2001)

3.4.3 Junction layout

Description

Channelisation at junction is intended to segregate traffic flows from each other and reduce the area of conflict between different intersecting traffic streams, provide junction angles to give good visibility and define driving patterns and indicate which road has priority. It can be carried out by using traffic islands (physical channelisation) or road markings (painted channelisation), can range from minor to full channelisation and can include left-turn, right-turn and passing lanes, depending on the type of the junction that is treated. More specifically, some of the investments that can be implemented are the installation of left-turn (single, dual or triple) or right-turn (single or dual) lanes to major-road approaches, the lengthening of existing ones, installation of right-turn acceleration lanes to major road approaches or left-turn acceleration lanes at divided highway junctions. The installation of medians (central reservation) to separate opposing lanes of traffic, or widening existing ones can also be considered. The implementation of shoulders on the secondary branches has also proven to have a positive effect on the road safety of junctions.

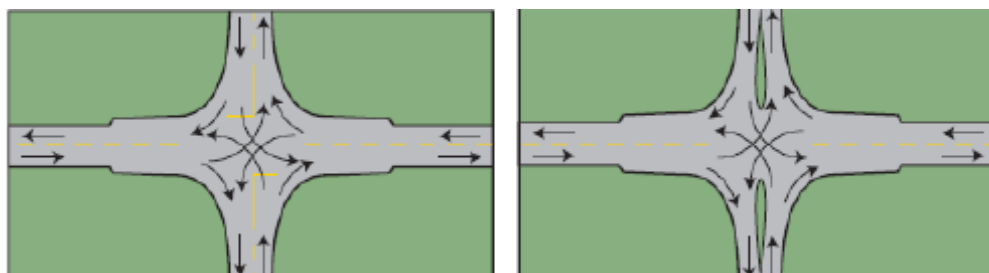


Figure 3.11. Junction channelisation

Four-arm junctions have higher accident rates than three-arm junctions, because they have more conflict points between the streams of traffic. According to Bared and Kaisar (Bared, Kaisar, 2001), one of the road safety treatments commonly used to reduce accidents at junctions is to stagger the junction (to convert a cross intersection into a pair of T-intersections).

Staggered junction aim at reducing the number of conflict points at junctions (Elvik, Vaa, 2004) and can be constructed in two ways: left-right staggering and right-left staggering.

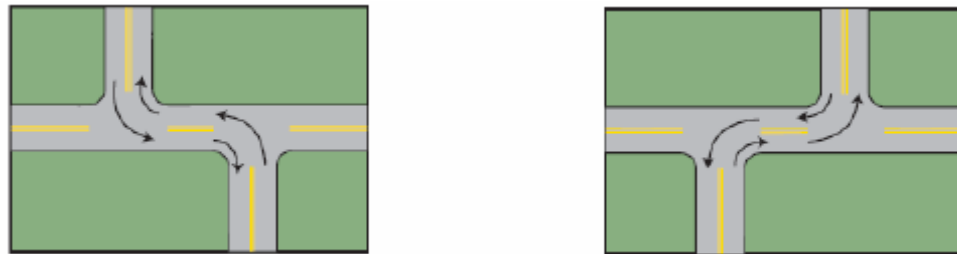


Figure 3.12. Junction staggering

Realignment of junction may concern a change of the angle between roads, changes to the gradients of the roads and / or any other additional measures that may improve sight conditions in the junction area.

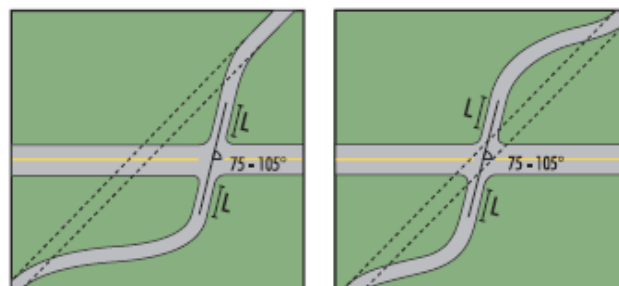


Figure 3.13. Junction realignment

Safety effect

The majority of the various forms of **channelisation** appear to have a more important effect on the number of accidents at crossroads than at T-junctions. There is a tendency that the more comprehensive the channelisation methods are, the more important the effect on accidents (ERSO, 2006).

The effect of **staggered junction** depends on the proportion of traffic of the secondary (minor) road at the crossroads before the staggering. Only when traffic of the secondary (minor) road is heavy can the number of injury accidents can be significantly reduced.

Research results concerning **junction's realignment** are very uncertain (Elvik, Vaa, 2004); it can be deduced that an angle of less than 90 degrees gives the fewest injury accidents and the opposite appears to be the case for material damage only accidents. A change in gradient on approaches to the junction from more than 3% to less than 3% appears to be associated with a reduction of the number of injury accidents, but with an increase of the number of material damage accidents. The effect of improving sight triangles at junction was not found to be statistically significant in some studies.

3.4.4 Traffic control at junctions

Description

The rule of giving way to traffic from the right applies for most (right-driving) countries for uncontrolled rural junctions. However, in most cases, road safety problems are encountered in uncontrolled junctions, in terms of increased accidents (material damage only and/or injury). In order to increase safety, improve traffic flow and simplify drivers' decision-making at uncontrolled junctions, different traffic and priority control schemes can be applied.

'Yield' signs at the approaches of a junction, together with appropriate road markings, are the simplest traffic control scheme aiming to improve giving-way.

'Stop' signs (two-way or all-way) intend to give drivers more time to observe traffic conditions at the junction and yield accordingly. In two-way stop junctions, drivers on the minor road should give way to drivers on the major road. In all-way stop junctions, the first-in / first-out rule applies (i.e. whoever arrives first, goes first).

Traffic signal control at junctions separates different traffic flows. Traffic signals can be either time-controlled (with a fixed number and duration of phases) or vehicle- (or user-) activated (the length of phases is optimised in relation to the number of vehicle arrivals at the junction or the number of pedestrians waiting, up to a certain maximum length). It is also possible that phases are shared between different traffic flows (e.g. right-turning drivers with pedestrians, or left-turning drivers with oncoming traffic).

Safety effects

Only a weak tendency towards accidents decrease is associated with the implementation of **'yield' signs** at uncontrolled junctions; the results of the available studies are very uncertain and the findings can not be statistically validated. One explanation for this limited safety effect may be the increase of speeds on the main road (Elvik, Vaa, 2004).

On the contrary, implementation of **'stop' signs** at uncontrolled junctions appears to have an important safety effect of around 20-45% reduction of injury accidents. Accordingly, implementation of **traffic signal control** appears to have a positive effect of around 30% at crossroads. The related figures for T-junctions are somewhat lower. It should be also noted that the effect may be quite different for different types of accidents.

Upgrading existing **traffic signal control**, such as reorganising phases, eliminating shared phases, establishing separate left-turn phases, introducing separate pedestrian phases etc. are associated with positive safety effects, although some of the existing results are somewhat uncertain.

Other effects

The implementation of 'yield' signs may bring an increase of travel speeds on the main road and a decrease in travel speeds on the minor road. In case of 'stop' signs, drivers on the minor road experience some delay. Traffic control also increases waiting times at junctions; however, in case of junctions with a high amount of traffic, traffic control may improve the total waiting times of all traffic streams. Although there are specific studies quantifying these effects in specific cases, their magnitude depends on the road and traffic conditions in each case.

As regards environmental effects, an increase in noise and emissions is confirmed by several studies dealing with 'stop' signs implementation.

Costs

Obviously, the implementation and maintenance costs of 'yield' and 'stop' signs are much lower compared to the related costs of traffic signal control schemes.

Cost-benefit analysis (CBA) examples

Given the uncertainty in the safety effect of 'yield' signs, no reliable cost-effectiveness results are identified. As regards 'stop' signs, examples examined by Elvik and Vaa (2004) show that the measure is cost-effective mainly in rural areas with low traffic. Traffic signal control appears to be cost-effective at crossroads, whereas no cost-effectiveness results for three-arm junctions are identified.

- A cost-effectiveness evaluation of implementation of traffic signal at rural junction yielded a marginally positive benefit to cost ratio of 1.25:1, by accounting for safety effects only. Time savings are considered as additional benefit (ROSEBUD, 2005)

3.5 Urban areas

3.5.1 Traffic calming schemes

Description

Traffic calming concerns a coordinated use of traffic engineering and control measures in a large area in order to improve traffic and environmental conditions (Elvik, Vaa 2004), by means of a reduction or ban of through-traffic, a reduction of travel speeds and a change of access and parking regulations in residential roads. **Traffic calming schemes** may include:

- Development of pedestrian streets
- Development of residential zones (woonerfs) (see Figure 3.14)
- Introduction of speed humps
- Reduction of speed limits
- Implementation of one-way traffic in residential streets
- Implementation of traffic and pedestrian signal control
- Development of reserved parking areas for residents

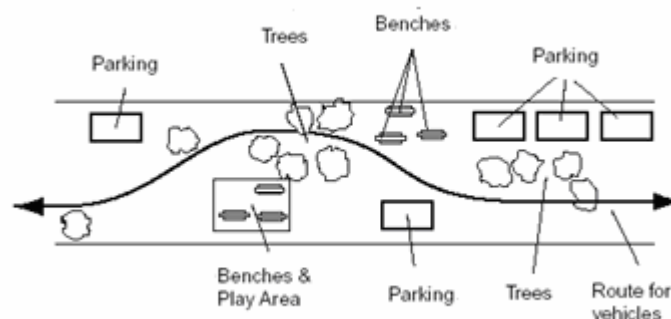


Figure 3.14. Ground plan of a residential zones (woonerf)

Each one of the above actions can be seen as a separate road safety measure; however, in area-wide traffic calming schemes, a combination of the above measures is used and in this case it is common practice to assess the efficiency of the entire scheme.

Safety effects

Several studies have dealt with the assessment of area-wide **traffic calming** schemes. Elvik and Vaa (2004) summarise the results of several studies and report significant safety effects in terms of injury road accidents, ranging from around 15% in the entire selected area to around 30% on the residential roads of the selected area. The results of other related case-studies (ROSEBUD, 2005) confirm these general trends.

Other effects

Noise levels are significantly reduced in residential roads of traffic-calmed areas; this is confirmed by several studies. As regards air pollution, important improvement can be observed, especially on local roads; the effect strongly depends on the reduction of traffic. However, part of the effect may be balanced by the fact that lower speeds and increased idling results in increased emissions. It is also noted that the positive environmental effects on residential roads are usually accompanied by negative effects on the main roads, which accommodate the traffic after the restrictions. Traffic calming has a negative effect on mobility (i.e. increased travel time), due to the through-traffic restrictions and the speed reduction.

It should be also noted that traffic calming schemes are sometimes faced with limited acceptability, as a result of the time disbenefit involved in their implementation.

Costs

The costs of area-wide traffic calming schemes vary significantly according to the type of traffic engineering measures implemented and the extent of the treatment area. On the other hand, implementation of lower cost traffic calming measures such as speed humps is possible. Maintenance costs should also be included into the implementation cost calculations.

Cost-benefit analysis (CBA) examples

The results of existing studies indicate that traffic calming schemes are generally characterised by a marginal to satisfactory cost-effectiveness (ROSEBUD, 2005, Elvik, Vaa, 2004). The fact that the traffic engineering measures are relatively of low-cost, together with the important safety effect to be expected, render this type of intervention cost-effective in the majority of cases. Care should be taken in the incorporation and quantification of (negative) mobility and (positive) environmental effects in the calculations.

- An extensive traffic calming scheme in a residential municipality of Athens, Greece, resulted in satisfactory benefit to cost results of around 1.8:1 (ROSEBUD, 2005).

3.5.2 Bypasses

Description

Bypasses are roads designed to carry long-distance traffic outside urban areas, so that conflicts between local traffic and long-distance traffic are avoided. In particular, bypasses aim to remove heavy and through-traffic from urban areas, in order to ensure better traffic and environmental conditions and improve the mobility of pedestrians, cyclists and other local users of the road network inside these areas. Bypasses are usually designed under interurban roads design principles, with increased speed limits, limited connection to the local road network and high standard junctions or interchanges for these connections.

The development of bypasses may also facilitate (or even initiate) the implementation of traffic calming schemes inside the urban area.



Figure 3.15. Bypass road

Safety effects

Several studies have identified important positive safety effects of **bypasses development**. The mean effect on injury accidents is estimated at around 25% reduction on both the bypass and the local road network. Moreover, the higher the accidents rate before the development of the bypass, and the higher the proportion of through-traffic that shifts from the urban road network to the bypass, the higher the safety effect of the bypass.

This safety effect, though, may be partly compensated by an increase of travel speeds inside the urban area, as a result of the reduction of traffic volume. In cases where the development of a bypass is combined with a reduction of speed limits or other traffic calming scheme inside the urban area, a more important safety effect should be expected.

Special attention should be paid to the intersections of the bypasses with existing road network, as in certain cases a significant number of accidents is observed at new intersections, especially during the first months following their implementation.

Other effects

Bypasses improve mobility for both the local and the long-distance motorised traffic. A positive effect for the mobility of pedestrians and cyclists due to the lower traffic volumes would also be expected, unless an increase of travel speeds is observed inside the urban area.

Positive environmental effects inside the urban area should also be expected, in terms of noise and emissions reduction, due to the reduction of congestion and heavy traffic. However, the development of a bypass is an intrusion to the landscape, which can be considered as a negative effect. Moreover, bypasses may result in urban sprawl and to a pattern of development inducing more transport in the long run (Elvik, Vaa, 2004)

Costs

Implementation and maintenance costs of bypasses may vary in relation to the type of bypass and the type of landscape.

Cost-benefit analysis (CBA) examples

Bypasses are characterised by high implementation and maintenance costs, but are also associated with positive safety, mobility and environmental effects. In general, such investments are expected to be very cost-effective. Again, the extent of cost-effectiveness depends on the road network and the broader area characteristics, being highly cost-effective in populated areas, with increased traffic volumes in the road network.

- ROSEBUD (2005) report marginal 1:1) cost - benefit ratios for development of bypasses in Sweden, probably due to low traffic volumes.

3.5.3 Improving land use regulations

Description

Studies have shown that the development of large areas without the direction of a long-term land usage plan may result in unnecessary traffic or a complicated and risky traffic system which can subsequently lead to more road accidents (Fridstrom et al., 1995). In urban areas, where the risk of injury road accidents per kilometre driven is higher than in rural areas, an increase in the size of the urban area may result in an increase of the accident rate. On this purpose land-use planning and land usage, can also be considered as road safety measures in certain cases. Defining specific activities that take place in an area (residential, commercial, industrial or mixed land usage) in such a way that traffic volume and travel distances are minimised, setting-up a road network that screens access roads from through traffic, designing individual roads with special specifications to ensure low accident risk and making the traffic system simple and easily understandable are only some of the actions that can be taken to improve the road safety level in urban or rural areas. In addition, ensuring the separation of pedestrians and cyclists and motor traffic at speeds of over 30 km/h in and around cities, towns and villages should be a high priority for land-use and network planning and ensure that safety becomes an inherent part of land use regulations. Even though the land use regulations are being improved in 65% of the CEDR countries, with the exception of Greece, only 16% of these countries plan to deal with this issue in the short or medium term, indicating that this road safety measure is not considered to be of very high priority among countries.

Safety effects

In general, land-use regulations and land usage can be linked with traffic safety not only by affecting the traffic volume in an area, but also the way in which traffic is distributed over the road network across different types of roads. Subsequently, it affects the choice of mode of transport and the accident rate on each road type (in particular on access roads in residential areas).

According to a relevant study quoted by Elvik and Vaa (2004), there is a strong negative relationship between development density and traffic volume, as an increase of development density by 50% (from 600m² to 300 m² per inhabitant) results to a reduction of the traffic volumes by approximately 33%. Traffic volumes are directly related to the accident rates and for example, all roads in urban areas have a higher rate for injury accidents than the average for public roads. The accident rate on access roads in densely populated areas is seven times the respective accident rate on motorways. Consequently more traffic on access roads in densely populated areas result in higher number of accidents. Building roads in such a way that through traffic is prevented and building short access roads in a way that speeds are kept low are some indicative ways to limit traffic volumes and therefore the number of accidents in the surrounding area.

Other studies indicate that in fully separated and differentiated residential areas fewer accidents are recorded than in areas not separated (change in health risk attributable to road accidents – 64%). With reference to the type of connection between the local and the main road network external feeding is associated with lower risk than internal feeding (change in health risk attributable to road accidents –33%). Finally, roads which cannot carry through traffic are safer than those permitting through traffic (change in health risk attributable to road accidents –72%). Relocation of workplaces and of industries within an area may have major consequences for transport and is another way to influence the traffic and subsequently the road safety level, as locating a business in the centre than on the outskirts of a city contributes to increasing the numbers using public transport and reduces the number of cars used to get to work (Elvik, Vaa, 2004).

Other effects

Land-use regulations also have effects on mobility, even though it is difficult to quantify them. It is proved however, that there is a tendency for the average speed to increase when the annual number of kilometres driven per inhabitant increases. Consequently it can be inferred that the average speed is higher in a dispersed development pattern with low density, and lower in a dense development pattern with relatively low land usage (Newman, Kenworthy, 1989)

Additionally, environmental issues which are closely related to road traffic are also influenced by land-use regulations in several ways, as in general, a land-use pattern that results to a reduction in traffic volume will lead to a reduction in noise and pollution. On the other hand, speed-reduction measures on access roads in residential areas can have adverse effects on both noise (due to noise increasing by the speed humps) and air pollution (at very low driving speeds the emission of exhaust gases increases).

Costs

The costs of land-use planning and the development of an area can vary considerably among countries but also among areas in the same country, depending on local conditions. The main factors that affect the costs are the area topography, the type of land and building, the building density, the installation of main technical systems etc.

Cost-benefit analysis (CBA) examples

Performing cost-benefit analysis of land-use planning, where costs and benefits of different development principles are quantified, is very difficult, as this measure has a large number of objectives, many of which are difficult to evaluate in monetary terms. As an example, in residential areas, among the qualities valued by people are the view, criminality rate, countryside, low living expenses, peace and quiet, whereas in industrial areas good accessibility is highly valued.

4 SELECTION OF MOST PROMISING INVESTMENTS

In the present Synthesis, the characteristics, safety effects and implementation costs of several infrastructure related investments were exhaustively analysed, following the initial work of CEDR (2006), in which a broad range of driver, vehicle and infrastructure related intervention areas had been assessed and ranked in short-, medium- and long-term priorities by the European Road Directors. This analysis was presented in the previous Chapters, where a first assessment of the eventual cost-effectiveness of the investments was proposed. In this Chapter, a summary and synthesis of the review results is presented. Furthermore, a final ranking of investments is carried out, in terms of investment characteristics, safety effects and implementation costs. The results are analysed and discussed within a preliminary selection of most promising road safety investments.

4.1 Summary of investments

In Table 4.1, various road safety investments are examined and the results are summarised on the basis of an exhaustive review. In particular, a list of the **examined road safety investments** is presented. The road safety investments in this list are classified according to the type of infrastructure where they can be implemented (motorways, rural roads, junctions, urban areas). It is noted that the proposed classification refers to the main type of infrastructure to which a road safety investment may be applied; in several cases, however, road safety investments may be applied to more than one type of infrastructure. The investments are also classified according to the investment area, i.e. the particular infrastructure element or operational feature to which the investment is applied (e.g. curvature, roadside, traffic control, etc.).

In particular, 55 specific road safety investments are analysed; these fall within 18 **investment areas**, each one belonging to one or more out of 4 infrastructure categories. The following analysis focuses on the individual investment level. In particular, it is specified in Table 4.1 whether each investment can be applied to simple road sections, bend sections, or junctions. Of these 55 investments, 36 can be applied to simple road sections, 38 investments can be applied to bend sections and 37 can be applied to junctions. Half of the investments can be applied to more than one infrastructure element, whereas 15 investments can be applied to all three infrastructure elements.

3. Both **the implementation costs and the safety effect** of each investment are ranked as 'high' or 'low', in accordance with the results of the review. In this synthesis, investments resulting in a statistically significant decrease in accidents are ranked as 'high', whereas measures showing a statistically non-significant decrease in accidents, or with marginal statistically significant decrease in accidents, or an increase in accidents, are ranked as 'low'. Moreover, investments with total costs not exceeding €50,000-60,000 (on average per unit of implementation) were ranked as 'low' cost (although these costs may vary from country to country).

It is noted that these rankings are based on an overall assessment, as the cost and safety effects of an investment may also depend on the scale of implementation (e.g. local or area-wide) or on the type of implementation (e.g. simple or more complex implementation). In a few cases, for which the review results are quite inconclusive, both 'high' and 'low' ranking values are used. Of the 55 investments analysed, 44 have a high safety effect (in general, or under certain conditions). However, only 25 of the 55 investments have low implementation costs.

In general, **an investment combining a high safety effect with a low implementation cost is considered to be an optimum solution**. Out of the 55 investments examined, 21 present high implementation costs and high safety effects, 4 present high implementation costs and low safety effects, 7 present low implementation costs and low safety effects, and 10 combine low implementation costs with high safety effects. It is also noted that 5 investments present high implementation costs and safety effects that may be either high or low, and 3 investments present low implementation costs and safety effects that may be either high or low. Finally, 4 investments have high safety effects and implementation costs that may be either high or low, and 1 investment has both high or low implementation costs and safety effects that may be high or low.

Number of Investissements examined	Implementation Cost	Safety effect
10	Low	High
21	High	High
3	Low	High/low
5	High	High/ILow
4	High/Low	High
1	High/Low	High/Low
7	Low	Low
4	High	Low
55		

Finally, an additional parameter examined in Table 3.1 concerns the acceptability of the implementation of the measures. This parameter is considered to be very important in the selection of the most promising investments and is also rated as 'high' or 'low'. However, it is important to emphasise that this is a general and rough assessment of the acceptability of each investment based on international experience. Overall, 47 of the 55 investments are expected to have high acceptability, whereas 6 investments may have high or low acceptability depending on the specific features of their implementation.

Table 4.1. Summary of Investments

	Investment Areas	Investments	Implementation Cost		Safety effect		Intervention Area			Acceptability		
			High	Low	High	Low	Bend	Junction	Section	High	Low	
Motorways	Development of motorways	Development of motorways	•		•		x	x	x	•		
	Development of interchanges	Development of interchanges	•		•*			x		•		
Rural roads	Horizontal Curvature treatment	Increasing curve radii	•		•		x			•		
		Introduction of transition curves	•		•		x			•		
		Reducing the frequency of curves	•		•	•	x			•		
		Superelevation treatment	•		•	•	x			•		
		Reducing gradient	•		•				x		•	
	Vertical curvature treatment	Reducing the frequency of curves	•			•	x			•		
		Improvement of sight distances	•				x	x	x	•		
		Increasing the number of lanes	•		•	•	x		x	•		
	Cross-section treatment	Increasing lane width	•		•**		x		x	•		
		Introduction of shoulder	•		•		x		x	•		
		Increasing shoulder width	•		•**		x		x	•		
		Introduction of median	•	•	•		x		x	•		
		Increasing median width	•		•	•	x		x	•		
		Introduction of 2+1 roads	•	•	•		x		x	•		
		Flattening side slopes	•		•		x		x	•		
	Roadside treatment	Establishment of clear zones	•		•		x		x	•		
		Implementation of safety barriers		•	•		x		x	•		
		Replacing safety barriers to meet the EN 1317 standard		•	•		x		x	•		
		Changing from unrestricted speed to speed limit		•	•		x	x	x		•	
	Speed limits	Lowering existing speed limit		•	•		x	x	x		•	
		Creation of speed transition zones	•	•	•			x	x	•	•	
		Traffic signs (regulatory)		•	•			x		•		
	Traffic Control and Operational Elements	Traffic signs (warning)		•	•	•	•	x	x	x	•	
		Traffic signs (guide)		•	•	•	•	x	x	x	•	
		Delineators and road markings		•	•	•		x	x			•
		Raised road markers		•	•	•		x	x			•
		Chevrons		•	•	•		x	x			•
Post-mounted delineators			•	•	•	•	x	x			•	
Rumble strips			•	•	•		x	x	x		•	
Navigation routing			•	•	•	•	x	x	x	•		
e-Safety Systems	Weather info VMS	•		•			x	x	•			
	Congestion info VMS	•		•			x	x	•			
	Individual info VMS	•		•	•		x	x	•	•		
	Vision Enhancement Systems	•		•		x	x	x	•			
	Ordinary resurfacing	•		•***		x	x	x	•			
Road surface treatment	Improving road surface evenness	•		•	•	x	x	x	•			
	Improving road surface friction	•		•***		x	x	x	•			
	Improving road surface brightness	•		•	•	x	x	x	•			
	Implementation of artificial lighting		•	•***	•***	x	x	x	•			
Lighting treatment	Improving existing lighting		•	•***	•***	x	x	x	•			
	Introduction of rail/road grade crossings	•		•			x		•			
Rail / road crossings treatment	Protection of rail/road level crossings		•	•			x		•			
	Development of roundabouts	Development of roundabouts	•		•		x		•			
Junctions	Junctions layout	Junction channelisation		•	•		x		•	•		
		Junction staggering	•		•***		x		•	•		
		Junction realignment	•		•	•	x		•			
	Traffic control at junctions	Implementation of yield signs		•	•	•		x		•		
		Implementation of stop signs		•	•	•***		x		•		
Implementation of traffic lights		•		•		x	x	•	•			
Improvement of existing traffic lights		•	•	•		x	x	•				
Urban areas	Traffic calming schemes	Traffic calming schemes	•	•	•	•	x	x	•	•		
	Development of bypasses	Development of bypasses	•		•***			x	•	•		
	Improvement of land use regulations	Improvement of land use regulations	•	•	•		x	x	•	•		

* refers to axis- or area-wide implementation

** refers to small or medium increase of width

*** depends on traffic volumes

Note: The safety effect here corresponds to a reduction of accidents. Both safety effect and implementation costs can vary between countries as they depend on national/local conditions

4.2 Identification of most promising road safety investments

As mentioned above, road safety investments with high safety effects and low implementation costs are preferable. Nevertheless, **road safety investments with high safety effects but high implementation costs must also be considered**. The infrastructure categories, investment areas and individual investments with high safety effects were identified and discussed, while particular attention was paid to those involving low implementation costs.

Road safety investments, such as motorway development or the introduction of interchanges, are associated with high safety effects, but they also involve very high implementation costs. The majority of the road safety investments examined can be considered to apply primarily to rural roads. No consistent cost-effectiveness pattern can be identified for this infrastructure category; in fact it is necessary to examine results at the level of investment area or individual investment. More specifically, infrastructure treatments such as curvature, cross-section, and road surface treatments are generally associated with high safety effects and high implementation costs, with a few exceptions for which the safety effects are not significant (e.g. reducing curves frequency). Additionally, investment areas relating to the overall road environment, such as speed limits and roadside treatments, are generally associated with high safety effects and relatively low implementation costs, although in some cases implementation costs may be increased (e.g. establishment of clear zones). On the other hand, traffic control and operational treatments have low implementation costs in most cases, but correspondingly also have relatively low safety effects. However, some individual investments in this area have high safety effects (e.g. warning and regulatory traffic signs at junctions, rumble strips). The investment area of eSafety systems is also promising: however, specific investments in this area, such as variable message signs (VMS), have high implementation costs, while the safety effects are uncertain.

As regards investments that are mainly applied to junctions, results are somewhat more consistent across investment areas. In particular, all investments have high safety effects. Infrastructure-related investments have high implementation costs (e.g. roundabouts, staggering), whereas traffic control-related investments have low implementation costs (e.g. 'stop' signs).

Finally, the urban area investments examined have high safety effects and high implementation costs. A special note refers to traffic-calming schemes and land-use rules, where implementation costs may vary according to the type of treatment.

Based on the above overall assessment, it can be stated that although no general rule can be formulated for a particular infrastructure category or investment area, individual investments that fulfil the optimum requirements can be found in all infrastructure categories and in most investment areas within those categories. It is important to note, therefore, that appropriate investments, which may be applied in cost-effective ways, either in the form of individual investments or sets of investments, exist for different types of infrastructure and various types of road safety problems.

Table 4.2 Preliminary assessment of the most promising investments

		Safety effect	
		High	Low
Implementation costs	LOW	Introduction of median (without widening of the road) Introduction of 2+1 roads Implementation of safety barriers Replacing safety barriers to meet the EN 1317 standard Lowering existing speed limit Changing from unrestricted speed to speed limit Creation of speed transition zones Traffic signs (regulatory) Traffic signs (warning)* Rumble strips Improvement of existing traffic lights Implementation of artificial lighting Improving existing lighting Protection of road/rail level crossings Junction channelisation Implementation of stop signs Minor traffic calming schemes* Improvement of land use regulations	Traffic signs (guide) Traffic signs (warning)* Delineators and road markings Raised road markers Chevrons Post-mounted delineators Navigation routing Implementation of yield signs Implementation of artificial lighting Improving existing lighting Minor traffic calming schemes*
	High	Development of motorways Development of interchanges Increasing curve radii Increasing the number of lanes* Introduction of transition curves Superelevation treatment* Reducing gradient Improvement of sight distances Increasing lane width Introduction of shoulder Increasing shoulder width Introduction of median (with widening of the road) Increasing median width* Introduction of 2+1 roads Flattening side slopes Establishment of clear zones Creation of speed transition zones Weather info VMS Congestion info VMS Individual info VMS* Vision Enhancement Systems Ordinary resurfacing Improving friction Introduction of rail/road grade crossings Development of roundabouts Junction staggering Junction realignment* Implementation of traffic lights Major traffic calming schemes* Development of bypasses Improvement of land use regulations	Reducing the frequency of curves (horizontal) Reducing the frequency of curves (vertical) Superelevation treatment* Increasing the number of lanes* Increasing median width* Individual info VMS* Improving road surface evenness Improving road surface brightness Junction realignment*

* Note: Safety effect and implementation costs can vary between countries as they depend on national/local conditions

A more detailed assessment of the safety effects and implementation costs of individual investments allows for the identification of the set of most promising investments. In Table 4.2, individual investments are classified in four categories, based on combinations of their rankings for safety effects and implementation costs (high or low).

In Table 4.2, the top-left section includes the low cost/high safety effect investments, the bottom-left section includes the high cost/high safety effect investments, the top-right section includes the low cost/low safety effect investments and the bottom-right section includes the high cost/low safety effect investments. It is worth noting that investments which may have either high or low safety effects or implementation costs are included in both ranks.

Priorities in road safety investments involve low cost/high safety effect investments. The corresponding top-left section of Table 4.2 includes 18 investments that fulfil or may fulfil all requirements. Readers will note that most of these investments involve speed management, traffic control, or light infrastructure treatments, which may be applied mainly at local level. Consequently, the items on this list can by no means address all requirements for road safety investment. In particular, in several cases, the road safety problems encountered require more complex or more extensive treatments. In such cases, it is unlikely that an effective solution can be found in the above list of low cost/high safety effect investments.

For this reason, other investments also need to be considered, in particular those in the high cost/high safety effect section. Despite their increased implementation costs, the increased safety effects of these investments result in marginal or satisfactory cost-effectiveness. These investments are included in the extensive list in the bottom-left section of Table 4.2. Readers will note that these 31 investments include a broad range of solutions, covering all types of infrastructure and investment areas. Moreover, several of these can be applied at area-wide level.

From the above results, it can be concluded that there is a significant number of cost-effective road safety investments that may be implemented to deal with various road safety problems. Existing research on the cost-effectiveness of road safety investments has provided both interesting results and useful evidence of the effectiveness of a range of road safety treatments.

The existing results allow for the selection of a set of investments that have important safety effects and could be considered to be best practice for cost-effective road safety infrastructure investments. In this set of investments, particular emphasis is placed on those that have high safety effects and preferably low implementation costs, namely those included in the left (mainly top-left) sections of Table 4.2.

In particular, the suggested most promising road safety investments in terms of cost-effectiveness mainly fall within five specific investment areas, summarised in Table 4.3 below.

Table 4.3. Selection of most promising investments for further analysis

- **Roadside treatments**
(clear zones, safety barriers)
- **Speed limits / Reduction of operating speed**
- **Junctions layout**
(roundabouts, realignment, staggering, channelisation)
- **Traffic control at junctions**
(traffic signs, traffic signals)
- **Traffic-calming schemes**

These most promising investments are analysed in more detail in the following sections in terms of safety effects, other (mobility, environmental, etc.) effects, and implementation costs. The cost-benefit ratio of the investments is subsequently presented. The cost-benefit ratio is considered to be an even more accurate and representative measure of cost-effectiveness than the cost-effectiveness ratio. The conditions under which the cost-effectiveness of each investment can be maximised or minimised are described and discussed, resulting in the identification of best practice. Moreover, on the basis of this in-depth analysis, the strengths and weaknesses of each of these most promising investments are presented and possible barriers to implementation are identified.

5 IN-DEPTH ANALYSIS OF MOST PROMISING ROAD SAFETY INVESTMENTS

5.1 Roadside treatment

5.1.1 Description

The **roadside** is defined as the area between the outside shoulder edge and the right-of-way limits (AASHTO, 2002) and is an important road element, affecting both accident severity and occurrence. The primary effect of an appropriate roadside configuration is first to reduce the probability of an accident, and if an accident does happen, to reduce the consequences of the accident, due to elimination of obstacles and absence of steep slopes. Consequently, the roadside area is a primary component in the creation of a forgiving road environment. The establishment of forgiving roadsides is one of the highest short-term priorities of Road Directors in Europe, as many Road Directors rank the treatment of trees and other roadside hazards, as well as the heightening of overall road standards among the most promising infrastructural measures regardless of the timeframe (CEDR, 2006).

Roadside treatments are mainly applied on interurban and rural roads. Roadside treatments mainly include flattening of **side slopes**, creation or extension of **clear zones**, introduction of appropriate marking and signalisation and removal or securing of roadside hazards. It is noted that a further distinction can be made between a "safety zone", defined as a zone adjacent to the road which is free of any obstructions which would be in the path of errant vehicles (in several countries, the shoulder is included in the "safety zone"), and a "recovery area", defined as a zone used mostly for recovery manoeuvres (but which can also provide extra space to avoid vehicles deviating from their normal paths, for emergency stopping of vehicles, for the circulation of bikes and pedestrians and so on) (RISER, 2007).

Moreover, **safety barriers** are often used, to prevent the collision with obstacles along the roadside, in case the obstacles themselves (e.g. trees) cannot be removed. According to the related EU standards for safety barriers (CEN, 1998), safety barriers should have adequate capacity allowing for deformation without failure. More specifically, EN 1317 is a performance specification adopted by the EU, which sets out the testing requirements for different classes of barriers. The relevant competent national authorities usually establish the need for a safety barrier.

The AASHTO Roadside Design Guide, defines the clear zone as the total roadside border area, starting at the edge of the travelled way, available for safe use by errant vehicles,. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. It is generally accepted that a wider clear zone creates a safer environment for potentially errant vehicles. According to various studies, a well-designed clear zone should have the following characteristics:

- i) Be of sufficient width that most vehicles that leave the road do not exceed its limits
- ii) Have up and down slopes that do not cause vehicle rollovers
- iii) Possess soil characteristics that do not lead to vehicle rollovers

Within the same context of making roadside obstacles-free zones, studies have been conducted on removal, or other treatments, of roadside obstacles. In a majority of countries, the following actions and steps are implemented (RISER, 2007):

1. Remove the obstacle
2. Redesign the obstacle so that it can be safely traversed
3. Relocate away the obstacle
4. Reduce impact severity by using an appropriate break-away device
5. Protect from the obstacle with a restraint system
6. Delineate the obstacle

Safety barriers are longitudinal barriers used to shield motorists from natural or man-made obstacles located along either side of road. They are designed to reduce the extent of damage and injury in the event of an accident and they are usually installed in places where it would be more dangerous to drive off the road or run into an obstacle, than to drive into them. The implementation of safety barriers can take place along the embankments and can include replacement of existing safety barriers by safety barriers designed to EN1317, installation of median safety barriers on divided highways or safety barriers between the lanes of opposing traffic on undivided highways. It is important though to note that safety barriers must be installed in a way that they do not obstruct driver's visibility or give a misleading impression of the road alignment.

5.1.2 Safety effects

The wider the roadside clear zone is, the higher is the probability than the accident will be avoided (PIARC, 2003). Zegeer et al. (1988) estimated the effects of **clear zone widening** on two-lane rural roads, and calculated the expected percentage reduction of “related accidents” (the total of run-off-road, head-on, and sideswipe accidents), ranging from 13% reduction for a 1,5m increase of the roadside clear recovery distance to 44% corresponding to a 6,2m increase. Additionally, according to an Australian study (Corben et al., 1997) the removal of roadside obstacles may result in a reduction of injury accidents by 2%, whereas marking the roadside obstacles may also be an alternative leading to significant accidents decrease (up to 23%).

Flattening side slopes reduces the probability of rollover in run-off road accidents and clear zones improve visibility and reduce the probability of collision with a fixed object (obstacle) in run-off road accidents. Both treatments are associated with significant safety effects (Graham, Harwood, 1982, Zegeer et al., 1988, Miaou, 1996). Neuman et al. (2003) report that rollover rates are significantly higher on slopes of 1:4 or steeper, comparing to slopes of 1:5 or flatter and concluded that single-vehicle run-off-road injury accidents (which include, but are not limited to rollovers) can be significantly reduced by flattening existing side slopes to 1:4 or flatter. Allaire et al. (1996) evaluated side slope flattening projects and run-off-road accident frequency and severity using a before-after study of 60 projects that involved side slope flattening for at least some portion of the project, finding a statistically significant benefit for slope flattening, as the reduction in run-off-road accident rates varied by comparison and by injury severity group from 3% -50%. According to a review of existing studies by Elvik and Vaa (2004) flattening a side slope from 1:3 to 1:4 reduces the number of injury accidents by around 40% and the number of material damage only accidents by around 30%. A further reduction of around 20% in the number of accidents is recorded when flattening from 1:4 to 1:6 and a possible explanation may be that flatter slopes make it easier to regain control over a vehicle leaving the road. Additionally, flatter slopes usually have fewer fixed obstacles than steeper slopes, and thus improved sight distances, which in turn may reduce the probability of collision with these obstacles.

As regards **safety barriers**, changing to safety barriers that meet the EN 1317 standard has a damage-reducing effect, but this is smaller than the effect of setting up safety barriers in places where previously there were none. Additionally, safety barriers do not have an equally great effect on all types of obstacles, as a significant reduction in the severity of injuries sustained in collisions with trees, rock faces and driving off the road in steep slopes is observed. The reduction in injuries is, however, smaller with regard to hitting signposts or ditches.

According to several studies reviewed by Elvik and Vaa (2004), setting-up **safety barriers along embankments** significantly reduces the number of fatal and injury accidents, especially in the event of running off the road. A reduction of 44% was recorded in the fatal accidents and a 47% decrease in the injury accidents. Changing guardrails along embankments to ones meeting the EN 1317 standards has also an important effect on the accidents, which is though slightly smaller.

With reference to the installation of **median safety barriers on divided highways**, an evaluation of a number of studies revealed a reduction in the number of fatal accidents by around 40% and a reduction in the number of injury accidents by 30%. At the same time though, an increase by around 25% in the number of material damage accidents was recorded, depending on the type of safety barrier installed (Elvik and Vaa, 2004). In Sweden, the installation of wire **median safety barriers on undivided highways**, aiming to prevent head-on collisions, revealed an increase of 32% in the number of material damage accidents. However, a significant reduction in the number of injuries was recorded (Carlsson et al., 2001).

In France, the implementation of a **combination of roadside safety measures** on a national road resulted in an important reduction of the number of accidents against trees, the respective fatalities and accident severity. More specifically, the combination of safety barriers installation along tree-lined stretches and cutting of roadside trees resulted to a 95% reduction of all accidents against trees (ROSEBUD, 2005).

According to data collected for The Netherlands, France and Spain by a questionnaire based survey focusing on the results of specific surveys on infrastructure related road safety measures in the various EU countries, the installation of safety barriers resulted in significant safety effects. More specifically, in 8 sites were treated in France, reductions of 17% and of 18% were observed in the number of road accidents and in the number of fatalities respectively. Additionally, a reduction of 50% in the number of injuries as well as in the number of all accidents was recorded in The Netherlands. Spain reported a decrease by 11% in the number of injury accidents and by 49% in the number of fatalities. Road safety experts from most European countries representing different areas of the European Union filled in the questionnaire, so that specific results of existing studies could be obtained. This survey took place in the framework of the activities of the O7 Task Group of the Road Safety Group of the Conference of European Directors of Roads (CEDR, Questionnaire 2).

It is noted, however, that in several countries (RISER, 2007), safety barrier treatments are a second priority for reducing the risk from roadside obstacles. The lack of specific quantitative results concerning other related treatments does not allow for a full comparative assessment of all roadside obstacle related treatments.

5.1.3 Other effects

Improved visibility may also lead to increased travel speeds, thus improving mobility. The environmental aspect may be more or less important, depending on the extent of the obstacle-free zone. However, the implementation of clear-zones includes major landscape interventions (deeper cuttings and higher embankments), which have important effect on the surrounding environment. Planting along embankments may reduce this negative effect.

Only a few studies on the effects of safety barrier installation on mobility have been identified, with one of the most recent indicating that in Sweden, the installation of median safety barriers on undivided highways resulted in an increase of the mean speed by 2km/h. It should be noted anyhow that this effect is strongly dependent on the distance between the safety barrier and the lanes.

Table 5.1. Safety effects of roadside treatment related investments

Source	Clear zones	Side slopes	Safety barriers	Description	Country / Region	Road network				Evaluation method		Safety effect (%)												
						Urban	Rural	Highways	Number of sites	meta-analysis	before/after	Best estimate	95% conf.int.	run-offroad and head-on accidents	single vehicle run-off accidents	single vehicle accidents with trees	all accidents	fatal accidents	injury accidents	Material damage accidents	fatalities	Injuries		
Corben et al., 1997	•			Marking of roadside obstacles	Australia	-	-	-	-	•		-23	s.s.											
Corben et al., 1997	•			Removal of roadside obstacles	Australia	-	-	-	-	•		-2	s.s.											
Zeeger et al., 1988	•			Increase of the roadside clear recovery distance on two-lane rural roads (between 1,5m - 6,2m)					-	•		(-13;-44)	s.s.	•										
ROSEBUD, 2005	•		•	Setting-up safety barriers and cutting trees	France		•		26,5 km	•		-95	(-59;-99)			•								
Elvik and Vaa, 2004		•		Flatten side slope from 1:3 to 1:4 mostly on two-lane roads	USA		•		-	•		-42	(-46;-38)									•		
Elvik and Vaa, 2004		•		Flatten side slope from 1:3 to 1:4 mostly on two-lane roads	USA		•		-	•		-29	(-33;-25)										•	•
Miaou, 1996		•		Flatten side slope from 1:3 to 1:4 mostly on two-lane roads			•		-	•		-28	s.s.		•									
Elvik and Vaa, 2004		•		Flatten side slope from 1:4 to 1:6 mostly on two-lane undivided roads	USA		•		-	•		-22	(-26;-18)										•	
Elvik and Vaa, 2004		•		Flatten side slope from 1:4 to 1:6 mostly on two-lane undivided roads	USA		•		-	•		-24	(-26;-21)										•	•
Miaou, 1996		•		Flatten side slope from 1:4 to 1:6 mostly on two-lane undivided roads			•		-	•		-24	s.s.		•									
Allaire et al., 1996		•		Flatten side slopes			•		60	•		(-3;-50)	-		•								•	
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	FR				8			-17	-											
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	FR				8			-18	-											•
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	NL				-			-50	-											
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	NL				-			-50	-											•
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	ES				-			-11	-											
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	ES				-			-49	-											•
CEDR (Questionnaire 2)			•	Setting-up safety barriers along embankments	ES				-			-26	-											•
Elvik and Vaa, 2004			•	Setting-up safety barriers along embankments	USA, AUS, SE		•	•	-	•		-44	(-54;-32)										•	
Elvik and Vaa, 2004			•	Setting-up safety barriers along embankments	USA, AUS, SE		•	•	-	•		-47	(-52;-41)											•
Elvik and Vaa, 2004			•	Changing safety barriers	USA, AUS, SE		•	•	-	•		-41	(-66;+2)											
Elvik and Vaa, 2004			•	Changing safety barriers	USA, AUS, SE		•	•	-	•		-32	(-42;-20)											
Elvik and Vaa, 2004			•	Median safety barrier on divided highways	USA, GB, FR, SE, DK		•	•	-	•		-43	(-53;-31)										•	
Elvik and Vaa, 2004			•	Median safety barrier on divided highways	USA, GB, FR, SE, DK		•	•	-	•		-30	(-36;-23)											•
Carlsson et al., 2001			•	Wire median safety barrier on undivided highways	SE			•		•		-23	-											•

s.s: statistically significant

Note: A negative safety effect corresponds to a reduction of accident

5.1.4 Implementation Costs

Cost figures concerning the implementation of clear zones and flattening side slopes could not be identified in the literature, however, it is commonly acknowledged that they are relatively high, varying significantly with the terrain conditions (e.g. the costs of these treatments increases significantly in areas with steeper slopes).

The costs for implementing a combination of roadside measures in France against collision with trees, concerned:

- i) Management of the road safety measure and report related to the ecological topic,
- ii) Implementation plans: topographical surveying, choices between safety barriers and tree cutting, frontage access treatments project report etc.,
- iii) Installation of the safety measure, safety barrier implementation, tree felling, road equipments and frontage access treatment,
- iv) Site supervision.

The total implementation cost was 993,000 € for 7.8 km of safety barriers. Additionally, in the Netherlands, the implementation cost for installing safety barriers account for 185,000 – 220,000 € per kilometer of road. It is noted that the cost of planning and analysis prior to the implementation should be also included in the implementation costs.

5.1.5 Cost-benefit (B/C) ratio

The costs of improving roadsides vary among countries and sites and no general rule can be deduced. For instance, flattening side-slopes can be more or less expensive according to the landscape. In general, though, flattening side-slopes and the establishment of clear zones have a higher implementation cost than implementing safety barriers or replacing existing safety barriers with ones meeting the EN 1317 standard. There are few specific studies on cost-effectiveness of such treatments and in general, the benefits are expected to be less than the costs. Elvik and Vaa (2004) report a Norwegian experience, according to which roadside safety barriers are cost-effective only on roads with an Average Annual Daily Traffic higher than 3.000.

However, in a cost-effectiveness evaluation of safety barriers implemented along the roadside in the rural road network of the "Landes" forest in France, to prevent collisions with trees, an impressive benefit to cost ratio of 8.7:1 was estimated (ROSEBUD, 2005). It should be noted, however, that the actual effectiveness depends on the occurrence of "collision with trees" type accidents. If other accidents are found (e.g. collision with animals or driveway collisions) this type of intervention has almost no effect. The cost effectiveness evaluation should therefore be associated with a detailed accident analysis.

Within the VESIPO project (2002), the implementation of roadside safety barriers on rural roads in Switzerland resulted in a benefit to cost ratio of 32:1.

5.1.6 Strengths, weaknesses and implementation barriers

The above analysis shows that roadside treatment can have important safety effects on accident severity, but also on the number of accidents. In particular, many different combinations of measures exist, ranging from simple ones (such as the installation or replacement of safety barriers along the embankments, the installation of median safety barriers, the removal or marking of roadside obstacles) to more complex ones, such as flattening side slopes and establishment of clear zones. The main strength of the investment may be identified in the high, consistent and well-documented safety effects, which appear to be independent of the extensiveness of the implementation of the measures.

Another strength concerns the acceptability of such treatments by the road users, as drivers feel more secure and protected when driving on roads where measures have been implemented to protect them from roadside obstacles or other road hazards.

A weakness of the roadside treatment is the relatively high implementation cost compared to other road safety measures, depending though on the type of treatment, the landscape and certainly the extent. The cost for installation of safety barriers or replacement of existing ones by ones meeting the EN1317 standards is relatively low, whereas other roadside treatments, such as establishment of clear zones and flattening of side slopes or combinations of measures, can be quite expensive and their effectiveness may also depend on other parameters (i.e. traffic volumes, etc).

Another weakness is the environmental effects of treatments such as the development of clear zones and flattening of side slopes. The flora and fauna of the surrounding area can be significantly damaged in case of specific roadside treatments and the cost for remoulding the landscape should also be considered in the overall implementation costs. Finally, the increase in the number of material damage accidents in a few cases can be considered as a weakness. However, this is more than compensated by the higher reduction of the accident severity and the lives saved.

A possible barrier to the implementation of some of the roadside treatments may concern the long and complicated administrative and financial procedures, especially as in some cases environmental approvals need to be obtained. These procedures involve several steps from the national to the regional and local levels.

5.1.7 Summary

The results of the above analysis are summarised in the following Table 5.2:

Table 5.2 Roadside treatment - summary of findings

<p>Investment: roadside treatment Network: mainly interurban / rural Sub-investments: (not considered separately)</p> <ul style="list-style-type: none"> - establishment of clear zones - flattening side slopes - installation of safety barriers along embankments - replacement of safety barriers to meet the EN 1317 standard - median safety barriers on divided highways / undivided highways - combination of safety barrier installation and roadside obstacle removal <p>Maximum safety effect:</p> <ul style="list-style-type: none"> ● installation or replacement of safety barriers (-47%) <ul style="list-style-type: none"> - especially when combined with other roadside works. <p>Minimum (or negative) safety effect:</p> <ul style="list-style-type: none"> ● flattening side slopes (-22%) <ul style="list-style-type: none"> - especially from 1:4 to 1:6 on two-lane undivided roads <p>Max. C-B ratio*:</p> <ul style="list-style-type: none"> ● safety barriers, considering only safety effects 32:1 <p>Min. C-B ratio*:</p> <ul style="list-style-type: none"> ● safety barriers, considering only safety effects 8.7:1 <p>Implementation costs per unit:</p> <ul style="list-style-type: none"> ● installation of safety barriers € 130,000 – € 220,000 per km, depending on type <p>Other effects:</p> <ul style="list-style-type: none"> ● negative effects on environment in some cases (e.g. tree removal) ● slight increase in average speed <p>Strengths:</p> <ul style="list-style-type: none"> - significant safety effects on the number of accidents with casualties, but also on accident severity - validated cost-effectiveness - high acceptability by road users <p>Weaknesses:</p> <ul style="list-style-type: none"> - relatively high implementation cost - side effects on the surrounding environment/landscape - slight increase in the number of damage-only accidents in some cases <p>Implementation barriers:</p> <ul style="list-style-type: none"> - potentially long and complicated administrative and financial procedures

* The available studies on the cost-effectiveness of such treatments are limited and concern specific cases. Results should, therefore, be considered with some caution.

5.2 Speed limits/reduction of operating speed

5.2.1 Description

Speed limits aim at setting a compromise between the mobility needs of drivers and the safety and environmental needs for all users of the road infrastructure. It has been demonstrated that there may be major differences in the speed at which different motorists drive given the same external conditions. Moreover, many drivers have an unrealistic expectation of being able to control their vehicle at much higher speeds than the posted speed limit. Within this framework, speed management includes a broad range of planning, engineering and intervening actions aiming to control and enforce vehicle travel speeds, reduce excess or inappropriate speed and ensure safer travel conditions for all road users, and at the same time ensure acceptable travel times and comfort in driving. This issue is a top priority for 34% of the countries, whereas for 35% of the countries it is of medium priority (CEDR, 2006).

Therefore, speed limit related investments, ranging from changes in national traffic rules to local interventions, aim at the improvement of road safety through the improvement of drivers' behaviour (Speed Alert, 2006). Therefore, it is obvious that the safety benefit will be largely dependent on the degree of police enforcement. A local speed limit without enforcement is usually characterised by a very low rate of compliance. The use of automated enforcement tools and average speed enforcing systems may cut down dramatically the rate of speeders.

Moreover, it should be underlined that any modifications of existing speed limits should be consistent with the standards of the road type examined. For instance significantly lowering speed limits on motorways might create inconsistencies between the function of motorways and the driving conditions induced by a too low speed limit, with negative mobility effects and significant discomfort for the drivers.

Within the current system of fixed speed limits, which is applied in most countries, the following **implementation steps** are important (ERSO, 2006):

- **Setting speed limits:** Speed limits need to reflect the safe speed on that particular road, related to road function, traffic composition, and road design characteristics. Furthermore, speed limits need to be credible, i.e. they must be logical in the light of the characteristics of the road and the road environment.
- **Information about the speed limit:** The driver must know, always and everywhere, what the speed limit is. The conventional way is to use consistent roadside signing and road markings. In-vehicle systems to inform drivers about the speed limit in force are likely to be introduced progressively.
- **Road engineering measures:** At particular locations low speeds may be crucial for safety (perceived or actual). Examples are near schools or homes for the elderly, at pedestrian crossings and at intersections. At these locations, physical speed reducing measures such as speed humps, road narrowing and roundabouts can help to ensure vehicles maintain a safe speed.
- **Police enforcement to control the intentional speeder:** If the three previous actions are applied, it can be assumed that the unintentional speed violations are an exception. Drivers who still exceed the speed limit do so intentionally. Police enforcement will remain necessary to control and punish that group of drivers.

Several actions and measures included in the above framework (e.g. traffic control and operational elements, e-safety systems, traffic calming) have been analysed in Chapter 3 of the present Report. This section analyzes **speed limits related investments**, which are the main tools of speed management and were also identified as some of the most cost-effective road safety investment.

A speed limit must reflect the function and quality of the road to ensure a safe speed limit. In addition, a speed limit must be supported by changes in the characteristics of the road and the road environment in order to be credible for the road user (ERSO, 2006). Although the speed limits used by different countries in different types of roads may vary considerably (Vis and Van Gent, 2007), de-facto standard in the EU is 80, 90 or 100 km/h in rural roads, 50km/h in urban areas, 30km/h in residential areas and 120km/h or 130km/h on motorways (CEDR, 2006).

Interventions and investments concerning speed limits can be of **different types** and may concern:

- introducing speed limits (changing from unrestricted speed limit to speed limit)
- lowering existing speed limits
- raising existing speed limits

These will be analysed exhaustively in the following sub-sections.

Complementary measures may concern speed transition zones, which help to indicate the transition from one traffic environment to another, from one traffic behaviour to another, and primarily to another speed (Herrsted et al. 1993). When entering the lower speed zone, in particular after a period of driving at a high speed (e.g. in the entrance of a village from a major through road), drivers will easily underestimate their travel speed, and hence insufficiently adapt their speed (ERSO, 2006). The first principle is that complementary measures along the through route within the urban area are required. The second principle is that measures at the transition zone should be such that they achieve a cumulative effect, culminating at the actual gateway to the towns or villages. The latter can be achieved by a combination of road narrowing and the introduction of vertical elements, culminating in the gateway (ETSC, 1995).

Another complementary measure, namely traffic calming, is analyzed in a separate chapter of this Report, being another most promising road safety investment.

5.2.2 Safety effects

An exhaustive literature review was carried out, concerning the safety effects of speed limits related investments. Although there are a great number of studies dealing with this issue, not many of them include the calculation of safety effects and their confidence intervals in the standard and recommended methodology. In the present Report, which aims at demonstrating best practices in implementing these investments, only statistically significant results based on the standard methodologies are presented, in order to avoid uncertain and confusing interpretation. These results are summarised in Table 5.3 and the main findings are briefly discussed below.

Introducing speed limits concerns changes from unrestricted speed to the use of speed limits; these investments have led to reductions in the number of accidents at all levels of severity. In particular statistically significant results of meta-analysis reported by Elvik and Vaa (2004) indicate that:

- In all speed limit reductions, fatal accidents are reduced by 11-13% on average and all accidents with casualties are reduced by 13% on average.
- In reduction from unrestricted speed limit to speed limit over 100km/h, fatal accidents are reduced by 11% and all accidents with casualties are reduced by 16%
- In reduction from unrestricted speed limit to speed limit from 80-97km/h, fatal accidents are reduced by 19% and all accidents with casualties are reduced by 22%

It can be deduced that the lower the speed limit set, the higher the safety benefit.

Lowering of speed limits concerns any change from a fixed speed limit to a lower speed limit. In this case, Elvik and Vaa (2004) report the following impressive results, based on meta-analysis:

- Lowering speed limit from 130 to 120 km/h, from 130 to 110 km/h and from 120 to 110 km/h results in 11% decrease of all accidents. No respective reduction as regards fatalities is expected, though.
- Lowering speed limit from 115 or 100 km/h to around 90 km/h (i.e. 88-97) results in 9% decrease of all accidents and up to 55% reduction of fatal accidents.
- Lowering any speed limit lower than 100 km/h (i.e. 90-80) by 15% on average is associated with important safety effects for all accidents (24% reduction). It is interesting to note that in this case the reduction of fatal accidents (43% reduction) is consistently almost twice the reduction in all injury accidents.
- Lowering any speed limit lower than 100 km/h (i.e. 90-80) by 15% on average is associated with important safety effects for all accidents (24% reduction). It is interesting to note that in this case the reduction of fatal accidents (43% reduction) is consistently almost twice the reduction in all injury accidents.
- Lowering any speed limit higher than 50 km/h (i.e. 50-60) by 15% on average is associated with impressive safety effects for all accidents (67% reduction).

It is noted that the effects become more significant once the initial speed limits are lowered to 85-90 km/h, indicating that this is the threshold where accident severity is significantly reduced. On the contrary, lowering the speed limit to 100 km/h still allows for travel speeds in which accidents are most likely to be fatal. Other relevant studies are consistent with the above findings:

- Lowering speed limit from 60 to 50 km/h in urban areas may result in 13% reduction of all accidents and 18% reduction in all casualties (Hoareau et al. 2006).
- Lowering speed limit from 110 to 100 km/h in rural areas may result in around 20% reduction of both accidents and casualties (Long et al. 2006).
- Lowering any speed limit in urban (residential) areas to 30 km/h may result in 15% reduction of both accidents and casualties (Lindenmann, 2005).
- A seasonal lowering of highway speed limits from 100 to 80 km/h during the winter time is associated with a statistically significant reduction in accidents of 14% (Peltola, 2000).

Accordingly, **raising speed limits** concerns changes from a fixed speed limit to a higher speed limit and these interventions are associated with consistently negative safety effects:

- A 15% raise of any fixed speed limit may bring an increase of 19% of all accidents and an increase of 26% of fatal accidents (Elvik and Vaa, 2004).
- Raising speed limits of interurban highways from around 90-105 to around 115-120 km/h leads to an increase of around 35% in fatalities (Patterson et al. 2002)
- Raising speed limits of interurban roads from lower than 105 to higher than 105 km/h leads to an increase of around 13% in fatalities (Shafi and Gentilelo, 2007)

- Raising speed limits of interurban highways from 90-100 to 115 km/h is expected to lead to a statistically significant increase of 3% in accident severity (Friedman et al. 2007)
- Raising speed limits in urban areas from 50 to 70 km/h is expected to lead to a significant increase of 15% in accidents. Further raise from 70 to 80 km/h is associated with an increase of 18% in all accidents and 36% in fatal accidents (Wong et al. 2005)

Certainly, raising speed limits is not a safety related intervention, however the above results are presented as a confirmation of the important effect of lower speed limits.

With respect to complementary measures, **speed transition zones** may also bear important safety benefits. Taylor and Wheeler (2000) evaluated the effects of 56 traffic-calming schemes in British villages on main interurban roads where the speed on the approach to the villages was typically 90 km/h. It was found that schemes with only gateway measures resulted in a reduction in fatal and serious accidents within the villages of 43%. The number of slight accidents increased by 5%. Higher accident reduction rates were reported for schemes with additional measures inside the villages (road narrowing, mini-roundabouts, speed humps), where the number of fatal and serious accidents decreased by about 70% and the number of slight injuries by about 37% (ERSO, 2006).

In general, speed limits safety effects are increased when these are systematically enforced and also combined with other road infrastructure measures (e.g. roadside improvements) (Cohen et al. 1998). Especially as regards enforcement, a combination of systematic enforcement and increased fines may in some cases double the safety benefit of speed limit related interventions. It must be emphasised that Police Enforcement is an integral part of any speed limit policy. The erection of speed limit signs, or changes in existing limits, without adequate police enforcement might not achieve the desired effect.

It is underlined, however, that the quantitative results presented in Table 5.3 concern either non-European cases, or meta-analysis providing the weighted mean effect of several countries (e.g. as in the results reported by Elvik and Vaa, 2004). These results are very consistent as regards the type of effects (positive or negative), however no specific national or local results from European countries were available. Although it is highly unlikely that totally different trends would be observed in a European context, the results of Table 5.3 should be considered with some caution as regards their relevance and transferability.

5.2.3 Other effects

In general, reducing speed limits reduces mobility, as travel time increases. On the other hand though, more equal distribution of travel speed may theoretically increase the capacity of the road infrastructure. Moreover, reducing speed limits and consequently travel speed is expected to bring environmental benefits, both in terms of noise and emissions. On the other hand, **raising speed limits may result in increase of noise and emissions**, although not enough scientific evidence is available on this issue.

Indicative results of related studies in the U.S.A. are the following:

- The raised speed limits (70 mph or higher) introduced in 23 U.S. States, following the elimination of the national 65 mph speed limit, have potentially produced significant increases in highway vehicle NOx emissions, and to a lesser extent CO. The most significant increases are in States with a large fraction of rural highways, like Texas or Montana (Pechan, 1997).
- The impact of speed limit changes 1 year after the elimination of the national 65 mph speed limit in the USA is estimated as an increase of 6%, 7%, and 2% of NOx, CO and VOC respectively. Much of the increase has occurred in western states, which generally have increased vehicle speeds more than in eastern and mid-western states. For example, in Texas NOx emissions are estimated to have increased by 35% due to large increases in highway and arterial speed limits (Mullen et al. 1997).

The lack of related studies at European level does not allow for a correct assessment of the magnitude and significance of these effects, and therefore the above results from Nordic countries and the U.S. are to be considered as indicative and not representative for the European countries. However, they provide a general indication for the environmental effects of speed limits raise, which may be considered by the appropriate authorities when evaluating the impacts of the specific investment.

It is also likely that an extensive use of speed limits may reduce the rate of drivers' compliance and thus reduce the effectiveness of the lowered speed limits.

5.2.4 Implementation Costs

The costs of speed limit related investments are relatively low, especially when they are implemented by means of traffic signs. Additional road engineering measures (e.g. speed humps) are also of relatively low cost in relation to other infrastructure treatments.

The costs of signposting in Norway is estimated at around 250-700 € per sign. Elvik and Vaa (2004) report that the average costs of signposting speed limits is around 300 € per kilometre of road.

The costs of accidents analysis, inspections and other activities related to planning, should be added to the implementation costs; however, these costs are not known.

Table 5.3. Safety effects of speed limits related investments

Source	Measure			From (km/h)	To (km/h)	Country / Region	Road network			Number of sites / sections	Year	Evaluation period	Evaluation method				Safety effect (%)										
	Introducing speed limits	Lowering speed limits	Raising speed limits				Interurban / Interstate	Rural	Urban / residential				meta-analysis	before/after (simple)	before/after (control group)	statistical model	Best estimate	95% conf.int.	all accidents	fatal accidents	injury accidents	all casualties	fatalities	other			
Elvik and Vaa, 2004	•			unrestricted	>100	-	-	-	-	-	-	•					-16		•								
Elvik and Vaa, 2004	•			unrestricted	>100	-	-	-	-	-	-	•					-11			•							
Elvik and Vaa, 2004	•			unrestricted	97-80	-	-	-	-	-	-	•					-22	(-20; -24)	•								
Elvik and Vaa, 2004	•			unrestricted	97-80	-	-	-	-	-	-	•					-19	(-3; -32)	•								
Elvik and Vaa, 2004		•		90-80	-15%	-	-	-	-	-	-	•					-24	(-31; -16)	•								
Elvik and Vaa, 2004		•		90-80	-15%	-	-	-	-	-	-	•					-43	(-60; -19)		•							
Elvik and Vaa, 2004		•		60-50	-15%	-	-	-	-	-	-	•					-67	(-76; -54)			•						
Peltola, 2000		•*		100	80	Finland	•			all main roads	1987	1987-1996					-14	s.s	•								
Hoareau et al., 2006		•		60	50	Victoria, Australia			•	all roads	2001	2001-2003			•		-13	(-23; -56)	•								
Hoareau et al., 2006		•		60	50	Victoria, Australia			•	all roads	2001	2001-2003			•		-18	(-22; -47)						•			
Elvik and Vaa, 2004		•		130-120	110	-	-	-	-	-	-	-	•				-11	(-10; -8)	•								
Elvik and Vaa, 2004		•		115-100	97-88	-	-	-	-	-	-	-	•				-9	(-10; -8)	•								
Elvik and Vaa, 2004		•		115-100	97-88	-	-	-	-	-	-	-	•				-54	(-62; -44)		•							
Long et al., 2006		•		110	100	Souht Australia		•		73 road sections	2003	2001-2005			•		-20	(-4; -44)	•								
Long et al., 2006		•		110	100	Souht Australia		•		73 road sections	2003	2001-2005			•		-19	n/a						•			
Lindenmann, 2005		•		any	30	Switzerland		•		all roads in 31 zones	-	3 years			•		-15	n/a	•								
Lindenmann, 2005		•		any	30	Switzerland		•		all roads in 31 zones	-	3 years			•		-15	n/a						•			
Lindenmann, 2005		•		any	30	Switzerland		•		all roads in 31 zones	-	3 years			•		-45	n/a						•			
Elvik and Vaa, 2004			•	any	+15%	-	-	-	-	-	-	-	•				+19	(+18; +20)	•								
Elvik and Vaa, 2004			•	any	+15%	-	-	-	-	-	-	-	•				+26	(+24; +28)		•							
Friedman et al. 2007			•	100-90	115	Israel	•					1988-1999		•		•	+3	s.s									•**
Patterson et al. 2002			•	105-89	113	USA	•			all roads in 23 states	1996	1992-1999			•	•	+35	(+6; +72)							•		
Patterson et al. 2002			•	105-89	120	USA	•			all roads in 23 states	1996	1992-1999			•	•	+38	(+8; +78)							•		
Wong et al. 2005			•	50	70	Hong Kong	•		•	19 sites	1999	1999-2005			•		+15		•								
Wong et al. 2005			•	50	70	Hong Kong	•		•	19 sites	1999	1999-2005			•		+1			•							
Wong et al. 2005			•	70	80	Hong Kong	•		•	19 sites	1999	1999-2005			•		+18		•								
Wong et al. 2005			•	70	80	Hong Kong	•		•	19 sites	1999	1999-2005			•		+36			•							
Shafi and Gentilello, 2007			•	< 105	> 105	USA	•			all main roads	2003	2003			•	•	+13	(+3; +24)							•		

* seasonal (winter)

** fatalities per 100 serious casualties

n/a: not available

s.s: statistically significant

Note: A negative safety effect corresponds to a reduction of accidents

5.2.5 Cost-benefit (B/C) ratio

From the above analysis, it is concluded that speed limit introductions and existing speed limits reductions may present **impressive safety effects**. The respective environmental effects are also expected to be positive, and the only negative effect may concern an increase of travel times (on a case-specific basis). Moreover, an extensive use of speed limits may reduce the rate of compliance and thus reduce the effectiveness of posted speed limits.

Moreover, the signposting of speed limits presents **very low costs**, compared to other road safety investments.

Consequently, the speed limit related investments are expected to be **very cost-effective**. Although no quantitative effects are available in the literature, Elvik and Vaa (2004) present some examples for Norway, according to which speed limits reduction is more cost-effective on rural roads, and in less populated areas in general. Winter speed limit is also considered to be cost-effective.

5.2.6 Effects on behaviour

Several studies have investigated the **effect of speed limit related investments on driver behaviour**, especially as regards speeding. The following results are indicative of the expected effects on driver behaviour:

- A research concerning the recent raise of speed limits on rural interstate roads in Indiana to 70 mph showed a wide range of factors (gender, age, income, number of children, age driver is first licensed, assessment of pavement quality, and assessment of vehicle manufacturers) influencing driving speed and that the effect of these factors changed as the posted speed limit changed (Mannering, 2007).
- Another study assessed how a 10 km/h raise in speed limit on 3 major interurban highways impacted road deaths in Israel. Result showed that speeds rose by 4.5% to 9.1% after the speed limit was raised (Richter et al. 2004)
- A case study on two road sections in Norway, where speed limits were changed from 90 to 80 or from 90 to 100 km/h, showed that on both roads the travel speed of adjacent sections changed in the same direction as the speed limit changed. However, the effects were rather small (1-2 km/h) (Sagberg, 2006).
- In the same framework, a study suggests that, allowing higher speeds on some highways not only causes higher speeds on local, connecting roads through speed adaptation, but also may cause higher speeds on other, unconnected and distant roads through some indirect process of speed generalization (Casey, 1992)

5.2.7 Strengths, weaknesses and barriers to implementation

From the above review it is indicated obvious that the effects of speed limit related investments on road safety can be extremely positive, namely in case of lowering speed limits. Consistent and well-documented effects have been identified, according to which introducing or reducing speed limits has important safety benefits in all area types and all speed limit ranges. Moreover, raising speed limits has been proved to deteriorate road safety. The consistency of these effects across different researches and case studies, together with the cost-effectiveness of the investments, due to the low implementation costs and the lack of very important side-effects can be considered as the main **strength** of speed related investments.

No important weaknesses of speed limit related investments have been identified, at least when these are correctly implemented. It can be assumed that any change in speed limits is expected to require an adjustment period from the part of drivers; however, this would be definitely overcome by the impressive safety benefit of the investment.

A **barrier** to implementation concerning speed limits investments can be considered with respect to the acceptability of the investment. In general, speed limit reductions are expected to have low acceptability among drivers, for whom speed and reliability in the transportation system is a priority; however, good acceptability of the investments can be expected in some cases, for instance among inhabitants in urban areas. Another possible limitation in the implementation of the investment may concern the administrative process. It is important to ensure consistency and continuity of posted speed limits in each case (e.g. all urban areas), which requires cooperation between national, regional and local authorities.

5.2.8 Summary

The results of the above analysis are summarised in the following Table 5.4.

Table 5.4. Speed limits - summary of findings

Investment: speed limits / lowering of operating speed

Network: interurban, rural, urban

Sub-investments:

- introducing speed limits (changing from unrestricted speed limit to speed limit)
- lowering existing speed limits
- raising existing speed limits

Maximum safety effect:

- lowering speed limits (-67%)
 - maximum safety effects for reductions on national and rural roads
 - the greater the reduction, the higher the safety effect

Minimum (or negative) safety effect:

- raising speed limits (+35%)
 - the higher the initial speed limit and the higher the increase, the greater the negative effect

Max. C-B ratio: not available

Min. C-B ratio: expected to be >1:1 due to low implementation costs

Implementation costs per unit:

- signposting speed limits ~ € 300 per kilometre of road

Other effects:

- lowering existing speed limits has positive effects on noise and pollution, and potentially negative effects on mobility
- raising existing speed limits has negative effects on noise and pollution, and potentially positive effects on mobility

Strengths:

- consistent and well-documented safety effects
- obvious cost-effectiveness

Weaknesses:

- no significant weaknesses

Implementation barriers:

- low acceptability
- co-ordination between national, regional, and local authorities

5.3 Junctions layout

5.3.1 Description

Junction layout treatments concern a broad range of investments, including junction type conversions and junction alignment improvements. In Chapter 3 of the present Report, several junction-related investments have been examined and it was found that junction layout investments are among the most promising road safety investments. In the present Chapter, the following investments are exhaustively analysed:

- Converting junctions to roundabouts
- Re-designing junctions
- Staggered junctions
- Junctions channelisation

Roundabouts are junctions with counter-clockwise (in right-driving countries) circulatory traffic. Roundabouts can improve traffic flow and road safety both in urban and rural areas, through a reduction of the traffic speeds, but also through the elimination or reduction of specific types of conflict points that typically occur at angular intersections (PIARC, 2003) (see Figure 5.1). The conflicts include left-turns against oncoming or opposing traffic, rear end accidents at junction approaches, and right-angle conflicts at both traffic signals and 'stop' signs. Roundabout specific configuration allows all traffic to come from one direction, uniform yielding rules (e.g. give way to users already in the roundabout), left turns in front of oncoming traffic are eliminated and travel speeds are reduced. As a matter of fact, only roundabouts with right of the way given to traffic already in the roundabout are effective for safety improvements.

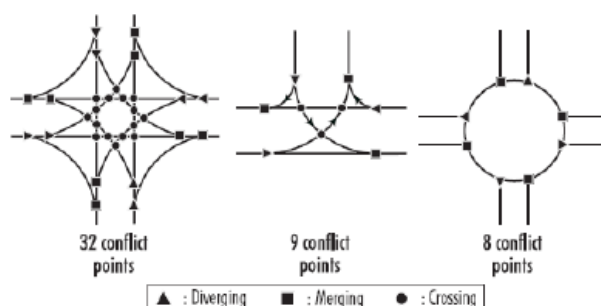


Figure 5.1. Conflict points of various junction types

Redesigning junctions may concern a change of the angle between roads, changes to the gradients of the roads and / or any other additional measures that may improve sight conditions in the junction area (e.g. increase of sight triangles) (PIARC, 2003). These investments are mainly implemented in rural areas.

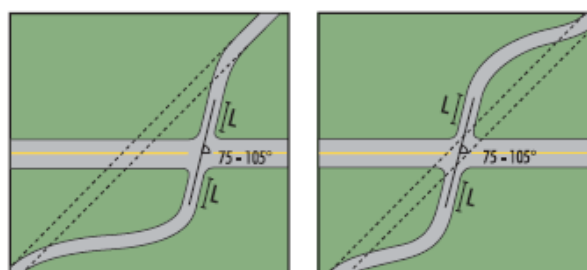


Figure 5.2. Junction re-alignment (PIARC, 2003)

Staggered junctions aim at reducing the number of conflict points at junctions (Elvik, Vaa, 2004) and can be constructed in two ways: left-right staggering and right-left staggering. In general, four-arm junctions have higher accident rates than three-arm junctions, because they have more conflict points between the streams of traffic. According to Bared and Kaiser (2001), one of the road safety treatments commonly used to reduce accidents at junctions is to stagger the junction (to convert a cross intersection into a pair of T-intersections). These investments are mainly implemented in rural areas.

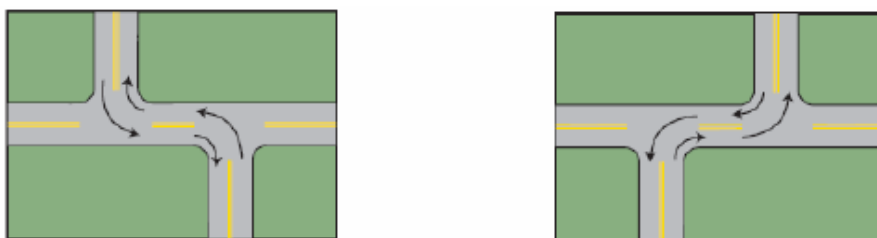


Figure 5.3. Junction staggering (PIARC, 2003)

Channelisation at junctions aims at segregating traffic flows from each other and reduces the area of conflict between different intersecting traffic streams, provide junction angles to give good visibility and define driving patterns and indicate which road has priority. It can be carried out by using traffic islands (physical channelisation) or road markings (painted channelisation), can range from minor to full channelisation and can include left-turn, right-turn and passing lanes, depending on the type of the junction that is treated (PIARC, 2003). More specifically, some of the investments that can be implemented are the installation of left-turn (single, dual or triple) or right-turn (single or dual) lanes to major-road approaches, the lengthening of existing ones, installation of right-turn acceleration lanes to major road approaches or left-turn acceleration lanes at divided highway junctions. Additionally, the installation of medians or widening existing ones can also be considered as channelisation treatment, as well as the implementation of shoulders on the secondary branches. These investments may be implemented both in urban and rural areas are proven to have a positive effect on the road safety of junctions.

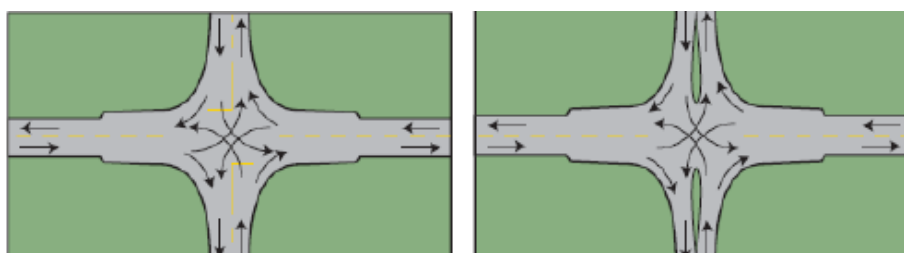


Figure 5.4. Junction channelisation (PIARC, 2003)

5.3.2 Safety effects

Although there are a great number of studies dealing with junction layout issues, not many of them include the calculation of safety effects and their confidence intervals in the standard and recommended methodology. In the present Report, only statistically significant results based on the standard methodologies are presented, in Table 5.5.

Important safety effects are associated with the **development of roundabouts** (Brenac, 1994). In particular, statistically significant results of meta-analysis reported by Elvik and Vaa (2004) indicate that:

- Converting stop-controlled junctions to roundabouts may result in 31% reduction of injury accidents for T-junctions and 41% reduction of injury accidents for crossroads.
- Converting traffic-signal-controlled junctions to roundabouts may result in 11% reduction of injury accidents for T-junctions and 17% reduction of injury accidents for crossroads.

Other related studies indicated the following:

- Converting stop-controlled single-lane urban and rural junctions to roundabouts may reach around 75% reduction of injury accidents and around 85% reduction of all accidents (Persaud et al. 2001).
- Converting traffic-signal-controlled single-lane rural junctions to roundabouts may result in around 35% reduction of injury accidents and 75% reduction of all accidents (Persaud et al. 2001).
- Converting any type of urban junction to a roundabout may result in around 45-50% reduction of injury accidents (Hyden and Varhelyi, 2000).

Moreover, the replies to the **Questionnaire 2 of the CEDR O7 Group** indicate the following experience in different countries with respect to replacing other junctions by roundabouts in different sites and conditions:

- France reports 70% reduction of accidents and 83% reduction of fatalities.
- The Netherlands report 55% reduction of accidents.
- Ireland reports 90% reduction of accidents and elimination of fatalities in the examined sites.
- Belgium reports 23% reduction of accidents and 32% reduction of fatalities in the examined sites in South Belgium.

In general, the installation of roundabouts results in substantial reductions to road accidents. This effect is systematically higher for fatal or serious injury accidents and lower for minor injury accidents. In some studies, the negative safety effect of roundabouts on material damage only accidents was identified. Moreover, roundabouts appear to have lower safety effect when replacing traffic-signal controlled junctions, than when replacing yield controlled junctions.

Research results concerning **junction re-designing** are in some cases uncertain; however, following meta-analysis presented by Elvik and Vaa (2004) based on examples from several countries, it can be deduced that:

- An angle of less than 90 degrees gives the fewest injury accidents and the opposite appears to be the case for material damage only accidents. Re-designing a junction of an angle less than 90° to an angle of 90°, may increase injury accidents by 80%. On the contrary, re-designing a junction of an angle of 90° to an angle of more than 90°, appears to bring a reduction of injury accidents by 50%
- A change in gradient on approaches to the junction from more than 3% to less than 3% appears to be associated with a (marginally significant) reduction of the number of injury accidents of 17%, but with an increase of the number of material damage only accidents.
- The effect of improving sight triangles at junctions was not found to be statistically significant in a number of studies analyzed by Elvik and Vaa (2004); meta-analysis results indicate negative safety effects of improving sight triangles at T-junctions (30% increase of injury accidents), and positive safety effects at 4-leg junctions (50% reduction of injury accidents). On the other hand, in the draft edition of the Highway Safety Manual (2005), a safety benefit of 73% is associated with increases of sight triangles.

Moreover, the replies to the **Questionnaire 2 of the CEDR O7 Group** indicate the following experience in different countries with respect to improving junction layouts in different sites and conditions:

- Ireland reports 54% reduction of fatalities from improvements in junction layouts, signs, sight triangles etc.
- Spain reports 70% reduction of accidents from general transformations in junction layouts.
- The UK reports around 70% reduction of accidents from improvements of the layout of the secondary branches in uncontrolled junctions.

The effect of **staggered junctions** appears to strongly depend on the proportion of traffic of the secondary (minor) road at the crossroads before the staggering. Only when traffic of the secondary (minor) road is important can the number of injury accidents be significantly reduced; moreover, adequate visibility and signalisation are necessary to achieve the maximum safety effects. Staggered junctions may result in 33% reduction of injury accidents when the traffic on the minor road is normal or heavy (Bared and Kaiser, 2001, Elvik and Vaa, 2004)

In general, the results concerning staggered junctions should be considered with some caution, given the small number of available studies and the important number of factors affecting the safety effect. For instance, the safety effect of staggered junctions may be partly due not to the staggering itself, but to the introduction of median islands, right-turn lanes and other forms of channelisation usually applied when implementing the staggering. Other effects, such as the elimination of continuity of the secondary traffic and the reduction of speed both on the primary and the secondary roads, may also be involved, but are extremely difficult to isolate and quantify. Moreover, the safety effects of staggered junctions are largely dependent on the amount of traffic, the distance between the two T-junctions and the various supplementary channelisation treatments.

The majority of the various forms of **channelisation** appear to have a more important effect on the number of accidents at crossroads than at T-junctions, although some of the existing results are rather uncertain. There is a tendency that the more comprehensive the channelisation methods are, the more important the effect on accidents (ERSO, 2006). In particular, Elvik and Vaa (2004) report the following, on the basis of meta-analysis:

- Introducing a painted left-turn lane on T-junctions may reduce injury accidents by 22%. The effect increases to 27% when the left-turn lane is physical.
- Introducing a physical left-turn lane on 4-leg junctions appears to reduce injury accidents by around 4%. The effect is negative (injury accidents appear to increase) when the left-turn lane is painted.
- Full physical channelisation (left- and right-turn lanes, medians etc.) may reduce injury accidents at 4-leg junctions by 27%.
- On the contrary, full physical channelisation at T-junctions is not associated with positive safety effects.

Other research, however, reports more positive and consistent results (Harwood et al. 2002):

- Introducing a painted left-turn lane on rural stop-controlled T-junctions may reduce injury accidents by 44%. The effect is reduced to 15% when the junction is signalised. The respective effects on urban T-junctions are 33% and 7% respectively
- Introducing a painted left-turn lane on rural stop-controlled 4-leg junctions may reduce injury accidents by 28%. The effect is reduced to 18% when the junction is signalised. The respective effects on urban T-junctions are 27% and 10% respectively

Moreover, the replies to the **Questionnaire 2 of the CEDR O7 Group** indicate the following experience in different countries with respect to channelisation treatments in different sites and conditions:

- The UK reports around 68% reduction of accidents from introducing left-turn lanes.
- The Netherlands reports around 20% reduction of accidents from introducing left-turn lanes.

5.3.3 Other effects

Roundabouts are generally characterised by lower travel speeds; however, drivers experience reduced **waiting times in roundabouts**, mainly due to the fact that they tend to accept smaller traffic gaps when crossing the roundabout. The overall improvement in mobility depends on the distribution of vehicles arrivals and the daily variations in traffic conditions; it is therefore difficult to establish a general rule. It has been found, though, that waiting times at signalised junctions are reduced heavily by the construction of a roundabout (Hyden and Varhelyi, 2000).

Re-designing junctions may improve mobility, to the extent that such changes improve sight triangles and the various features of the approaches to the junctions; however, such effects are difficult to consider in a generalised way.

Table 5.5. Safety effects of junction layout related investments (1/2)

Source	Measure				Changing from	To	Country / Region	Road network		Number of sites	Year	Evaluation period	Evaluation method			Safety effect (%)				
	Roundabouts	Re-designing junctions	Staggered junctions	Channelization				Rural	Urban / residential				meta-analysis	before/after (control group)	statistical model	Best estimate	95% conf. int.	all accidents	fatalities	injury accidents
Elvik and Vaa, 2004	•				4-leg, stop controlled	roundabout	-	-	-	-	-	•			-41	(-47;-34)			•	
Elvik and Vaa, 2004	•				T-junction, stop controlled	roundabout	-	-	-	-	-	•			-31	(-45;-14)			•	
Elvik and Vaa, 2004	•				4-leg, signalized	roundabout	-	-	-	-	-	•			-17	(-22;11)			•	
Elvik and Vaa, 2004	•				T-junction, signalized	roundabout	-	-	-	-	-	•			-11	(-40;+32)			•	
Hyden and Varhelyi, 2000	•				various	roundabout	SE, Vaxjo	•	2	1991	5 years later	•			-50	s.s			•	
Hyden and Varhelyi, 2000	•				various	roundabout	SE, Vaxjo	•	21	1991	6 months later	•			-44	s.s			•	
Persaud et al. 2001	•				Single lane, stop controlled	roundabout	USA	•	8	1992-1997	15 months later	•			-88	s.s	•			
Persaud et al. 2001	•				Single lane, stop controlled	roundabout	USA	•	5	1992-1997	15 months later	•			-82	s.s	•			
Persaud et al. 2001	•				Single lane, stop controlled	roundabout	USA	•	8	1992-1997	15 months later	•			-72	s.s			•	
Persaud et al. 2001	•				Single lane, stop controlled	roundabout	USA	•	5	1992-1997	15 months later	•			-58	s.s			•	
Persaud et al. 2001	•				Signalized	roundabout	USA	•	4	1992-1997	15 months later	•			-74	s.s	•			
Persaud et al. 2001	•				Signalized	roundabout	USA	•	4	1992-1997	15 months later	•			-35	s.s			•	
CEDR (Questionnaire 2)	•				various	roundabout	IE	-	5	-	-				-100				•	
CEDR (Questionnaire 2)	•				various	roundabout	FR	-	41	-	-				-83				•	
CEDR (Questionnaire 2)	•				various	roundabout	FR	-	41	-	-				-71		•			
CEDR (Questionnaire 2)	•				various	roundabout	NL	-	-	-	-				-55		•			
CEDR (Questionnaire 2)	•				various	roundabout	South Belgium	-	122	-	-				-32				•	
CEDR (Questionnaire 2)	•				various	roundabout	South Belgium	-	122	-	-				-23		•			
CEDR (Questionnaire 2)	•				various	roundabout	IE	-	5	-	-				-90		•			
CEDR (Questionnaire 2)		•			various	general transformation	IE	-	-	-	-				-100				•	
CEDR (Questionnaire 2)		•			various	general transformation	FR, Loire Atlantique	-	57	-	-				-89				•	
CEDR (Questionnaire 2)		•			various	general transformation	FR, Loire Atlantique	-	57	-	-				-74		•			
CEDR (Questionnaire 2)		•			various	general transformation	ES	-	-	-	-				-70		•			
CEDR (Questionnaire 2)		•			uncontrolled junction	Improvement of secondary branches	UK	-	14	-	-				-69		•			
CEDR (Questionnaire 2)		•		•	various	signs, revised layout, left-turn lane, increased sight triangles	IE	-	118	-	-				-54				•	
Elvik and Vaa, 2004		•			Angle 90 degrees	Angle >90 degrees	-	-	-	-	-	•			-50	(-70;20)			•	
Elvik and Vaa, 2004		•			4-leg junction	Increased sight triangles	Nordic counties and USA	-	-	-	-	•			-48	n/a			•	
Elvik and Vaa, 2004		•			-	Reduced gradient on approach	-	-	-	-	-	•			-17	(-30;-3)			•	
Elvik and Vaa, 2004		•			-	Increased sight triangles	Nordic countries	-	-	-	-	•			-3	(-18;+14)			•	
Elvik and Vaa, 2004		•			t-junction	Increased sight triangles	Nordic counties and USA	-	-	-	-	•			+29	n/a			•	
Elvik and Vaa, 2004		•			Angle <90 degrees	Angle 90 degrees	-	-	-	-	-	•			+80	(+20;+170)			•	
Highway Safety Manual, 2005*		•			-	Increased sight triangles	UK	-	11	-	-				-73					

Table 5.5. Safety effects of junction layout related investments (2/2)

Source	Measure				Changing from	To	Country / Region	Road network			Year	Evaluation period	Evaluation method			Safety effect (%)				
	Roundabouts	Re-designing junctions	Staggered junctions	Channelization				Rural	Urban / residential	Number of sites			meta-analysis	before/after (control group)	statistical model	Best estimate	95% conf.int.	all accidents	fatalities	injury accidents
Elvik and Vaa, 2004		•			4-leg junction, heavy minor road traffic	two T-junctions	Nordic counties and USA	-	-	-	-	-	•			-33	(-43;-21)			•
Elvik and Vaa, 2004		•			4-leg junction, low minor road traffic	two T-junctions	Nordic counties and USA	-	-	-	-	-	•			+35	(+10;+70)			•
Bared and Kaiser, 2001		•			4-leg junction, signalized, heavy minor road traffic	two T-junctions	California, USA		•	45	-	7 years		•		-25	s.s			•
Elvik and Vaa, 2004			•		T-junction	plus physical right-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			-2	(-50;+90)			•
Elvik and Vaa, 2004			•		T-junction	plus painted left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			-22	(-45;+11)			•
Elvik and Vaa, 2004			•		T-junction	plus physical left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			-27	(-48;-3)			•
Elvik and Vaa, 2004			•		T-junction	plus physical full channelization	Nordic counties, UK and USA	-	-	-	-	-	•			+16	(0;+36)			•
Elvik and Vaa, 2004			•		4-leg junction	plus painted left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			+28	(-14;+92)			•
Elvik and Vaa, 2004			•		4-leg junction	plus physical left-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			-4	(-25;+22)			•
Elvik and Vaa, 2004			•		4-leg junction	plus physical right-turn lane	Nordic counties, UK and USA	-	-	-	-	-	•			-13	(-83;+348)			•
Elvik and Vaa, 2004			•		4-leg junction	plus painted full channelization	Nordic counties, UK and USA	-	-	-	-	-	•			-57	(-68;-42)			•
Elvik and Vaa, 2004			•		4-leg junction	plus physical full channelization	Nordic counties, UK and USA	-	-	-	-	-	•			-27	(-37;-15)			•
Harwood et al., 2002			•		T-junction, stop controlled	plus painted left-turn lane	USA		•	280	-	9-13 years	•			-33	s.s			•
Harwood et al., 2002			•		T-junction, stop controlled	plus painted left-turn lane	USA	•		280	-	9-13 years	•			-44	s.s			•
Harwood et al., 2002			•		4-leg, stop controlled	plus painted left-turn lane	USA	•		280	-	9-13 years	•			-28	s.s			•
Harwood et al., 2002			•		4-leg, stop controlled	plus painted left-turn lane	USA		•	280	-	9-13 years	•			-27	s.s			•
Harwood et al., 2002			•		4-leg, signalized	plus painted left-turn lane	USA	•		280	-	9-13 years	•			-18	s.s			•
Harwood et al., 2002			•		Stop controlled	plus painted right-turn lane	USA		•	280	-	9-13 years	•			-14	s.s			•
Harwood et al., 2002			•		4-leg, signalized	plus painted left-turn lane	USA		•	280	-	9-13 years	•			-10	s.s			•
Harwood et al., 2002			•		T-junction, signalized	plus painted left-turn lane	USA	•		280	-	9-13 years	•			-15	s.s			•
Harwood et al., 2002			•		T-junction, signalized	plus painted left-turn lane	USA	•	•	280	-	9-13 years	•			-7	s.s			•
Harwood et al., 2002			•		Signalized	plus painted right-turn lane	USA	•	•	280	-	9-13 years	•			-4	s.s			•
CEDR (Questionnaire 2)			•			plus left-turn lane	UK	-	-	22	-	-				-68				•
CEDR (Questionnaire 2)			•			plus left-turn lane	NL	-	-	-	-	-				-20				•
CEDR (Questionnaire 2)			•			plus right-turn lane	NL	-	-	-	-	-				-1				•

n/a: not available
s.s: statistically significant
* draft edition

Note: A negative safety effect corresponds to a reduction of accidents

Staggered junctions may be associated with different mobility effects. **Right-left staggered junctions induce shorter travel times** than both left-right staggered junctions and four-leg junctions, in the sense that drivers coming from the minor road have to give way to only one traffic stream, i.e. when turning to the right on to the main road (Mahalel et al, 1987). Elvik and Vaa (2004) estimated that, for an hourly traffic volume of 1,000 vehicles, the difference in waiting times between right-left staggering and left-right staggering is around 15 seconds per vehicle. Bared and Kaiser (2001) suggest that these time savings may reach 20 seconds per vehicle, when the entering flow are higher than 2,300 vehicle/h. Moreover, their findings from a typical right-left design indicated that this treatment could be detrimental to traffic operations when the offset between the two T-intersections is not long.

Channelisation treatments at junctions aim at improving mobility by reducing waiting times for vehicles travelling straight through the junction, since those vehicles will not have to wait behind vehicles turning left or right. It appears, however, that **mobility effects of channelisation are largely dependent on the amount of traffic** on the main road; channelisation seems to reduce delays only when both the amount of traffic going straight and the amount of traffic turning left are high (Craus and Mahalel, 1986).

Concerning **emissions**, a reduction may be expected when replacing traffic-signal controlled junctions by roundabouts, and an increase when replacing yield-controlled junction by roundabouts. Again, no general conclusion can be drawn on this issue and it is recommended to examine these effects on case-specific basis.

On average, emissions (CO and NOx) at roundabouts replacing non-signalised junctions may increase by between 4 and 6%, while a roundabout replacing a signalised junction may lead to a reduction by between 20 and 29%. The noise level is also reduced at junctions that are replaced by roundabouts (Hyden and Varhelyi, 2000). Another study also gave very positive performance results for a roundabout compared with a traffic signal junction, and it was found that the average driving speed through the junction in one direction could be increased by 50%, and as a result of this, emissions per vehicle could be decreased by 35% (Hoglund, 1994).

The **environmental effects** of re-designing junctions, staggering junctions or creating channelisation have not been examined in the existing literature. It can be assumed, however, that some of these treatments may increase the total junction area.

5.3.4 Implementation Costs

The **costs of roundabout development** may range from 450,000-1,300,000 €. Converting a T-junction to a roundabout is estimated at around 650,000 €, whereas the respective costs for four-leg junctions is estimated at around 450,000 €.

The **costs of re-designing junctions** may vary significantly for different types of treatment. Elvik and Vaa (2004) report that the costs for a complete reconstruction of a junction in Norway are estimated at around 785,000 € in 1995 prices. Sight triangles improvements in Sweden are estimated at around 6,800 € (1980 prices) per junction, however the range of costs largely depends of the extent of the treatments.

Staggering junctions imply the construction of at least one new intersection. The **cost of a staggered junction** in Norway is estimated to range from 130,000 -1,300,000 million €.

Elvik and Vaa (2004), provide indicative **costs for various forms of channelisation** for Norway, underlining that 50% local variations may be expected:

- Left-turn lane at T-junction: 65,000 €
- Left-turn lane at four-leg junction: 100,000 €
- Full channelisation at T-junction: 1,300,000 €
- Full channelisation at four-leg junction: 1,650,000 €

The costs of accidents analysis, inspections and other activities related to planning, should be added to the implementation costs; however, these costs are not known.

5.3.5 Cost-benefit (B/C) ratio

Elvik and Vaa (2004) estimated the Benefit / Cost ratio of converting junctions to roundabouts in Norway at a range from 1.80:1 (T-junctions) to 2.20:1 (4-leg junctions). From the Questionnaire 2 of the CEDR 07 Group, Ireland reports a Benefit / Cost ratio of 2.95:1.

Moreover, in the ROSEBUD Handbook (2006) provides respective results for urban areas for Norway at 1.23-8.61:1, and in the Czech Republic at 1.5:1.

With respect to junction re-alignment, no results are available, except one reported from Ireland in the Questionnaire 2 of the CEDR 07 Group, concerning a combination of junction treatments including warning signs, revised layout, road markings, surfacing, right turn lanes and improved sight distance. The Benefit / Cost ratio is estimated at 3.8:1. Elvik and Vaa (2004) suggest that junction re-alignment related treatments shall be cost-effective in Norway if their costs are lower than 70,000 €.

Staggered junctions are expected to be marginally cost-effective; Elvik and Vaa (2004) present examples for Norway, according to which the Benefit / Cost ratio of the investments shall be positive if the investments costs are lower than 650,000 €.

Channelisation treatments are also expected to be cost-effective, although no results are available. Elvik and Vaa (2004) present indicative examples for Norway, according to which minor channelisation of 4-leg junctions are expected to have a Benefit / Cost ratio of around 2.7:1, whereas full channelisation of 4-leg junctions are expected to have a Benefit / Cost ratio of around 1.1:1

5.3.6 Effects on behaviour

An extensive study following the replacement of junctions by roundabouts revealed that the roundabouts resulted in a **better interaction between road users** in the following ways (Hyden and Varhelyi, 2000):

- The 'main road behaviour syndrome', i.e. to drive as if one always has the right of way, decreased 4 months after the rebuilding.
- The behaviour of motorists coming from side roads became almost equal to the behaviour of those coming from main roads.
- Drivers showed more consideration to vulnerable road-users in the after situation. Bicyclists were more respected by motorists compared to the "before" situation, and pedestrians on zebra crossings got priority from vehicles twice as often as before the rebuilding

Moreover, from the results of follow-up interviews 4 years after the implementation of the roundabouts, it was concluded that all road users were satisfied with the roundabouts.

No results were found to be available with respect to the effect of redesigning or staggering junctions, and the effect of junction channelisation on road users behaviour.

5.3.7 Strengths, weaknesses and implementation barriers

The main weakness of this type of investments is that **their cost-effectiveness is largely dependent on the implementation costs**, which are not always very low. Obviously, the more extensive the treatments, the higher the costs; for instance, staggered junctions require the construction of at least one new junction. However, the safety effects are not necessarily higher in more extensive treatments.

Therefore, a second, minor weakness concerns the fact that safety effects are less consistent in relation to those of other types of investments and several exceptions or particularities may be identified.

Due to the increased number of particular cases when considering the effectiveness of junctions, it is more **difficult to establish general rules**, and there may be a somewhat higher degree of uncertainty with respect to the cost-effectiveness of junction layout improvements. However, numerous studies exist on the safety and other effects of these investments and the necessary information is available for almost all types and particular cases of junction layout treatments. This **extensive literature** may be considered as the main strength of junction layout treatments.

5.3.8 Summary

The results of the above analysis are summarised in the following Table 5.6:

Table 5.6. Junction layouts - summary of findings

Investment: junction layouts	
Network: rural / urban	
Sub-investments:	
-	converting junctions to roundabouts
-	redesigning junctions
-	changing the junction angle, staggered junctions, reducing gradients on approach, increasing sight triangles (mainly rural areas)
-	junction channelisation
Maximum safety effect:	
●	converting junctions to roundabouts (-88%)
●	changing the junction angle (-50%)
●	channelisation at 4-leg junctions (-57%)
-	the more extensive the channelisation, the highest the safety effect
Minimum (or negative) safety effect:	
●	channelisation at T- junctions (+16%)
●	reducing gradients on approach (-17%)
●	staggered junctions (low traffic on minor road)
Max. C-B ratio:	
●	converting junctions to roundabouts 2:1 to 3:1
●	redesigning junctions 3:1
●	junction channelisation 2.5:1 (refers to minor channelisation)
Min. C-B ratio:	
●	high cost redesigning junctions
●	high cost channelisation
Implementation costs per unit*:	
●	converting junctions to roundabouts € 450,000 - 1,300,000
●	redesigning junctions from € 1,100,000
●	staggered junctions € 130,000 - 1,300,000
●	junction channelisation € 25,000 - 1,650,000
●	development of mini roundabout € 12,000
Other effects:	
●	improved mobility (except left-right staggered junctions, for channelisation only when traffic is high)
●	effects on noise and emissions
●	in some cases the total junction area increases
Strengths:	
-	well-documented effect for all types and particular cases of treatments
Weaknesses:	
-	rapid decrease in cost-effectiveness for more extensive treatments, due to increase in implementation costs
-	difficult to establish general rules due to the high number of case-specific situations

**The above costs are indicative implementation costs based on specific case-studies. Costs per unit depend on junction layout and local situation.*

5.4 Traffic control at junctions

5.4.1 Description

Traffic control at junctions was found as one of the most promising investments for the improvement of road safety. In this section, specific features of traffic control related investments are discussed in order to identify best practices in the implementation of such investments. The types of traffic control examined include:

- implementation of 'yield' signs
- implementation of 'stop' signs
- implementation of traffic signals
- upgrade of traffic signals

Within this framework, the above measures shall be examined in two ways: first, when introduced at an uncontrolled junction and, second, when replacing a previous type of traffic control at a junction. In the latter case, replacement to both more and less advanced traffic control schemes is investigated (e.g. replacing 'stop' signs with traffic signals and vice versa). As regards the upgrade of traffic signal control, it is noted that advanced schemes (e.g. user- or vehicle- actuated traffic signals, network coordinated traffic signal control etc.) are not examined in detail.

Traffic control at junctions aims to increase safety, improve traffic flow and simplify drivers' decision-making. At uncontrolled junctions, road safety problems are encountered in terms of increased accidents (material damage only and/or injury). The rule of giving way to traffic from the right applies for most (right-driving) countries for uncontrolled rural junctions; however, different traffic and priority control schemes can be applied for the purpose of improving road safety at junctions.

'Yield' signs at the approaches of a junction, together with appropriate road markings, are the simplest traffic control scheme aiming to improve giving-way.

'Stop' signs (two-way or all-way) intend to give drivers more time to observe traffic conditions at the junction and yield accordingly. In two-way stop junctions, drivers on the minor road should give way to drivers on the major road. In all-way stop junctions, the first-in / first-out rule applies (i.e. whoever arrives first, goes first).

Traffic signal control at junctions separates different traffic flows. Traffic signals can be either time-controlled (with a fixed number and duration of phases) or vehicle- (or user-) actuated (the length of phases is optimised in relation to the number of vehicle arrivals at the junction or the number of pedestrians waiting, up to a certain maximum length). It is also possible that phases are shared between different traffic flows (e.g. right-turning drivers with pedestrians, or left-turning drivers with oncoming traffic). It is noted however that traffic signal control is mostly implemented in urban areas; some countries (e.g. France) have almost abandoned traffic signal control at rural junctions, largely applying roundabouts instead.

Moreover, an **upgrade of traffic signal control** may include redesigning of the number and duration of phases, reduction or elimination of shared phases, establishment of user- or vehicle-actuated phases, and so on.

5.4.2 Safety effects

Traffic signal control at junctions is associated with significant positive road safety effects, which are analysed below and are summarised in Table 5.7. According to these results, there is a small tendency towards higher safety effects of more advanced traffic control schemes.

According to a meta-analysis of results from Nordic countries, USA and Australia by Elvik and Vaa (2004), only a small tendency towards accidents decrease is associated with the **implementation of 'yield' signs** at uncontrolled junctions; the results of the available studies are rather uncertain and the findings can not be fully validated statistically. One explanation for this limited safety effect of 'yield' signs may be an increase of travel speeds on the main road. In particular, introducing yield signs at uncontrolled junctions is associated to a marginally significant reduction of injury accidents by 3%

On the contrary, **implementation of 'stop' signs** at uncontrolled junctions appears to have an important safety effect. Interestingly, statistically significant results are available, according to which, replacing traffic signals with 'stop' signs improves road safety on one-way roads. More specifically:

- Introducing one-way 'stop' signs at T-junctions may reduce injury accidents by around 20% (Elvik and Vaa, 2004)
- Introducing two-way 'stop' signs at four-leg junctions may result in a significant reduction of injury accidents by 35%, while introducing all-way 'stop' signs at four-leg junctions may result in a respective reduction of 45% (Elvik and Vaa, 2004)
- Replacing traffic signals by 'stop' signs on urban one-way roads may result in a reduction of injury accidents by 24%, and a reduction of pedestrian accidents by 18% (Persaud, 1997)

In the CEDR Questionnaire 2, UK reports a 68% accident reduction associated with traffic signs improvements, whereas in Spain the respective effect was 14%.

Implementation of traffic signal control appears to have positive effects on road safety outcomes. The related figures for T-junctions are somewhat lower than the ones for four-leg junctions, though. It should also be noted that the effect may be quite different for different types of accidents. In particular:

- Introducing traffic signals at T-junctions may reduce injury accidents by around 15% (Elvik and Vaa, 2004)
- Introducing traffic signals at 4-leg junctions may reduce injury accidents by around 30% (Elvik and Vaa, 2004)
- Introducing traffic signals at 4-leg junctions may reduce rear-end accidents by around 35% (Golias, 1997)

Upgrading existing traffic signal control, such as reorganising phases, is associated with positive safety effects, although some of the existing results are rather uncertain. These upgrades can be roughly classified into two large groups: the first group concerns changes in the duration of phases (e.g. re-timing or coordination of traffic signals, introduction of interactive traffic signals), and the second group concerns changes in the number of phases (e.g. eliminating shared phases, establishing left-turn phases, introducing separate pedestrian phases etc.).

As regards the safety effects of the first group of treatments concerning changes in the duration of phases, the following statistically significant results are available:

- Re-timing traffic signals, in order to improve the phases, may reduce injury accidents at junctions by 12% and pedestrian accidents at junctions by 37% (Retting et al. 2002)
- Switching from fixed phases to vehicle- or user-actuated phase changes may reduce all accidents at junctions by 25% (Elvik and Vaa, 2004)
- Network coordinated traffic signals (e.g. "green wave") is associated with a reduction of injury accidents at junctions of around 20% (Elvik and Vaa, 2004)

As regards the safety effects of the second group of treatments concerning changes in the number and type of phases, the results are slightly more uncertain, however some specific trends can be identified (Elvik and Vaa, 2004):

- Introducing mixed phase pedestrian signals appears to marginally increase pedestrian accidents by 8%, whereas a separate phase pedestrian signal appears to reduce pedestrian accidents by 30%
- Introducing a left-turn phase is associated with a significant reduction of all accidents of 10%, which may reach 60% in the case of separate left-turn phase
- On the other hand, right-turn permission during the red signal may increase injury accidents by 50-70%. It is noted, however, that this procedure tends to be rarely implemented in most countries in the last few years.

According to the CEDR Questionnaire 2, introducing traffic signals in France resulted in 36% reduction of accidents and 67% reduction of fatalities. Introducing traffic signals in the UK resulted in 38% reduction of accidents; when a separate pedestrian phase was introduced, the safety benefit reached 53%.

Table 5.7. Safety effects of junction traffic control related investments

Source	Measure				Description	Country / Region	Road network			Evaluation period	Evaluation method		Safety effect (%)						
	Yield signs	Stop signs	Traffic signals	Upgrade of traffic signals			Rural	Urban / residential	Number of sites		meta-analysis	before/after (control group)	Best estimate	95% conf.int.	all accidents	fatalities	injury accidents	pedestrian accidents	rear-end accidents
Elvik and Vaa, 2004	•				introducing yield signs at junctions	Nordic countries, USA, AUS	-	-		-	•		-3	(-9;+3)			•		
CEDR (Questionnaire 2)	•	•			general improvement of signs	UK	-	-	7	-			-68		•				
CEDR (Questionnaire 2)	•	•			general improvement of signs	ES	-	-		-			-14		•				
CEDR (Questionnaire 2)	•	•			general improvement of signs	ES	-	-		-			-23			•			
Elvik and Vaa, 2004		•			4-leg junctions, introducing four way STOP	Nordic countries, USA, AUS	-	-		-	•		-45	(-49;-40)			•		
Elvik and Vaa, 2004		•			4-leg junctions, introducing two way STOP	Nordic countries, USA, AUS	-	-		-	•		-35	(-44;-25)			•		
Elvik and Vaa, 2004		•			T-junctions, introducing one way STOP	Nordic countries, USA, AUS	-	-		-	•		-19	(-38;+7)			•		
Persaud, 1997		•	•		replacing traffic signals by two-way STOP, one way roads	Philadelphia, USA		•	71	1978-1992		•	-18	s.s.					•
Persaud, 1997		•	•		replacing traffic signals by two-way STOP, one way roads	Philadelphia, USA		•	71	1978-1992		•	-24	s.s.					•
CEDR (Questionnaire 2)			•		introducing traffic signals	FR			6				-67			•			
CEDR (Questionnaire 2)			•		introducing traffic signals	FR			6				-36		•				
CEDR (Questionnaire 2)			•		introducing traffic signals	UK			11				-38		•				
Elvik and Vaa, 2004			•		T-junctions, introducing traffic signals	Nordic countries, USA, AUS	-	-		-	•		-15	(-25;-5)			•		
Elvik and Vaa, 2004			•		4-leg junctions, introducing traffic signals	Nordic countries, USA, AUS	-	-		-	•		-30	((-35;-25)			•		
Golias, 1997			•		4-leg junctions, introducing traffic signals	Athens, Greece		•	48	1985-1997		•	-36	(-44;-28)					•
CEDR (Questionnaire 2)			•		introducing pedestrian signal - separate phase	UK	-	-	6	-			-53		•				
Elvik and Vaa, 2004			•		introducing pedestrian signal - separate phase	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		-30	(-40;-15)					•
Elvik and Vaa, 2004			•		introducing pedestrian signal - mixed phase	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		+8	(-1;+17)					•
Elvik and Vaa, 2004			•		introducing left-turn phase	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		-10	(-15;-5)	•				
Elvik and Vaa, 2004			•		introducing left-turn phase-separate	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		-58	(-64;-50)	•				
Elvik and Vaa, 2004			•		vehicle-actuated phase changes	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		-25	(-33;-15)	•				
Elvik and Vaa, 2004			•		coordinated signals (green wave)	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		-19	(-22;-15)				•	
Retting et al. 2002			•		re-timing traffic signals	New York, USA	•	•	122	1991-1997			-12	s.s.				•	
Retting et al. 2002			•		re-timing traffic signals	New York, USA	•	•	122	1991-1997			-37	s.s.					•
Elvik and Vaa, 2004			•		right-turn permission during red signal	Nordic countries, DE, NL, UK, USA, AUS	-	-		-	•		+60	(+50;+70)				•	

s.s: statistically significant

Note: A negative safety effect corresponds to a reduction of accidents

5.4.3 Other effects

The implementation of 'yield' signs may bring an increase of **travel speeds** on the main road and a decrease in travel speeds on the minor road. In case of two-way 'stop' signs, drivers on the minor road experience some delay, whereas in case of all-way 'stop' signs, all drivers experience some delay.

Traffic control also increases **waiting times** at junctions; however, in case of junctions with a high amount of traffic, traffic control may improve the total waiting times of all traffic streams. Although there are specific studies quantifying these effects in specific cases, their magnitude depends on the road and traffic conditions in each case.

As regards **environmental effects**, an increase in noise and emissions is confirmed by several studies dealing with 'stop' signs implementation.

However, environmental benefits are associated with the improvement of traffic signals operation. For instance, increasing cycle length or increasing the proportion of green time appears to significantly reduce pollution (Matzoros and Van Vliet, 1992).

5.4.4 Implementation Costs

Obviously, the implementation and maintenance costs of 'yield' and 'stop' signs are much lower compared to the related costs of traffic signal control schemes.

The **costs of signposting and road markings** in Norway is estimated at around 250-700 € per sign.

The average **cost of implementing traffic signal control** at junctions is estimated between 50,000 € and 300,000 € depending on the size and the local conditions, whereas maintenance costs are estimated at 4,000 € per year (Elvik and Vaa, 2004).

The costs of accidents analysis, inspections and other activities related to planning, should be added to the implementation costs; however, these costs are not known.

5.4.5 Cost-benefit (B/C) ratio

Given the uncertainty in the safety effect of 'yield' signs, no reliable cost-effectiveness results are identified.

As regards 'stop' signs, examples examined by Elvik and Vaa (2004) show that the measure is cost-effective mainly in rural areas with low traffic. In particular, results indicate a Benefit / Cost ratio of 6.8:1 for rural T-junctions in Norway. However, cost-benefit ratio was found negative for urban 4-leg junctions, due to vehicle delays and negative environmental effects.

It is noted, however, that Germany reports a cost-benefit ratio higher than 3:1 in the Questionnaire 2 of the CEDR O7 Group.

Traffic signal control appears to be cost-effective at crossroads only. Elvik and Vaa (2004) calculated negative cost-benefit ratio for installing traffic signals at T-junctions in Norway. On the contrary, traffic signals at 4-leg junctions were attributed a cost-effectiveness of 8:1.

In ROSEBUD (2006) a cost-benefit ratio of 1.25:1 was calculated for introducing traffic signal control at rural junctions in Israel.

Elvik and Vaa (2004) report that upgrading traffic signals in Norway is expected to have a cost-benefit ratio equal to 8.6:1.

Finally, Germany reports cost-benefit ratios higher than 3:1 in the Questionnaire 2 of the CEDR O7 Group, both for the introduction and the upgrade of traffic signals.

5.4.6 Effects on behaviour

A recent study on the **crossing behaviour at uncontrolled intersections** of Swedish drivers showed that different groups of drivers could be identified according to their strategies of yielding behaviour. One group of drivers reported that they rarely yielded, whereas another group reported that they always did so. A third group complied with the right-hand rule most of the time, whereas the behaviour of a fourth group varied over intersections (Bjorklund and Aberg, 2005). These results indicate the usefulness of implementing traffic control at junctions.

Another research study investigated the **danger compensation effect**, which may occur where safety improvements installed at a site lead to a decrease in road safety elsewhere in the traffic system, due to the tendency of drivers to adjust their behaviour so as to compensate for the safety measures used. This hypothesis was tested with respect to **'stop' signs implementation**, by measuring drivers' approach speeds at the next junction after the junction where the 'stop' sign had been installed. It was found that the percentage of infrequent commuters exceeding the speed (48 km/h) at which they could just have stopped their vehicles at the test intersection increased relative to the stop-controlled junction from 12 to 25%. This increase was again observed at a four-month follow-up. However, the regular commuters showed no such increase. Accordingly, it was concluded that the behaviour of some infrequent commuters was consistent with the danger compensation hypothesis (Smith and Lovegrove, 1983).

Sisiopiku and Akin (2001) found that proper traffic control at junctions can significantly encourage pedestrian to cross at designated locations; in this research, the effect of the availability of pedestrian signal to influence pedestrian decisions to cross at a specific location was quite high (around 74%).

5.4.7 Strengths, weaknesses and implementation barriers

From the above exhaustive review it is obvious that the effects of traffic control related investments on road safety at junctions can be very positive, namely in case of implementing or upgrading traffic signals. The consistency of these effects across different researches and case-studies can be considered as the main **strength** of these investments.

A **weakness** of traffic control related investments concerns the important negative environmental effects, identified and reported by a number of studies. Although these may be significantly reduced in some cases (e.g. coordinated traffic signals), in most cost-efficiency assessments they may limit the important safety benefits, compromising the overall cost-benefit ratio of the investments. However, the cost-benefit ratio is still expected to be positive in most cases.

Finally, the main **implementation barrier** related to traffic control related investments concerns the limited acceptability of such investments by drivers, especially in rural and generally less populated areas.

5.4.8 Summary

The results of the above analysis are summarised in the following Table 5.8:

Table 5.8. Traffic control at junctions - summary of findings

Investment: traffic control at junctions	
Network: rural / urban	
Sub-investments:	
<ul style="list-style-type: none"> - implementation of 'yield' signs - implementation of 'stop' signs - implementation of traffic signals (mainly urban areas) - upgrade of traffic signals (mainly urban areas) 	
Maximum safety effect:	
● implementation of all-way 'stop' signs at 4-leg junctions	(-45%)
● implementation of traffic signals at 4-leg junctions	(-36%)
● upgrade of traffic signals	(-37%)
- introducing separate left-turn or pedestrian phases	
Minimum (or negative) safety effect:	
● implementation of traffic signals	(+60%)
- mixed pedestrian phase	
- right-turn permission during red signal	
Max. C-B ratio:	
● implementation of 'stop' signs	6.8:1 at rural T-junctions
● implementation of traffic signals	8:1 at 4-leg junctions
● upgrade of traffic signals	8.6:1
Min. C-B ratio:	
● implementation of 'stop' signs	may be negative at 4-leg junctions
● implementation of traffic signals	may be negative at T-junctions
Implementation costs per unit:	
● signposting	€ 250 – 700 per sign
● implementation of traffic signals	€ 50,000 – 300,000 per junction
	€ 4,000 annual maintenance costs
Other effects:	
● increased delays (except for the major road when 'yield' or 'stop' signs are implemented on the minor road)	
● increased noise and emissions (except green-wave traffic signals)	
Strengths:	
- significant, consistent and well-documented safety effects	
Weaknesses:	
- sensitive to environmental effects in urban areas	
Implementation barriers:	
- low acceptability	

5.5 Traffic calming schemes

5.5.1 Description

Traffic calming concerns a coordinated use of traffic engineering and control measures in a large area in order to improve traffic and environmental conditions (Elvik, Vaa 2004), by means of a reduction or ban of through-traffic, a reduction of travel speeds and a change of access and parking regulations in residential roads. **Traffic calming schemes** may include:

- Development of pedestrian streets
- Development of residential zones (woonerfs) (see Figure 5.5)
- Introduction of speed humps
- Reduction of speed limits
- Implementation of one-way traffic in residential streets
- Implementation of traffic and pedestrian signal control
- Development of reserved parking areas for residents

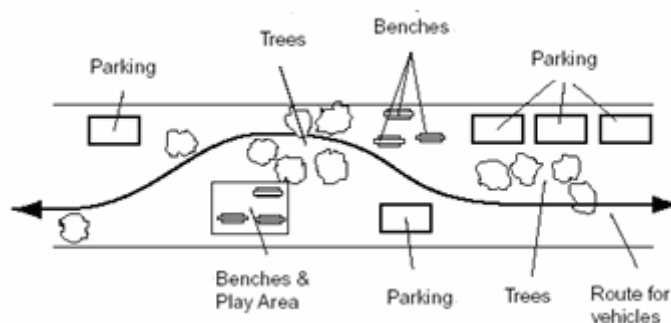


Figure 5.5. Ground plan of a residential zone (woonerf)

Each one of the above actions can be seen as a separate road safety measure; however, in area-wide traffic calming schemes, a combination of the above measures is used and in this case it is common practice to assess the efficiency of the entire scheme.

According to the ITE's Traffic Engineering Handbook (ITE, 1999), three levels of traffic calming can be generally defined:

1. Level III (Metropolitan) Traffic Calming involves a global network planning approach of setting objectives with strategies and actions designed to achieve the goal of a reduction of travel. The metropolitan level of traffic calming can only be achieved by introducing appropriate measures into long and short range plans.
2. Level II Traffic Calming relates to measures that bring the explicit consideration of safety to modifications to existing cross sections and land use adjacent to the arterial road system.
3. Level I Traffic Calming comprises the traditional approach to site-specific calming techniques and traffic calming deployed to the local street system.

Most area-wide traffic calming schemes focus on the management of vehicles by means of physical devices and are typically found in residential areas, with the purpose of reducing traffic volume and driving speed on residential access roads (Level I). As a result of the installation of speed humps in 23 sites in the city of Cagliari, Italy in 1990, vehicle speed was reduced by 10% - 17% and approximately two thirds of the drivers kept their speed below the posted speed limit (Pau, Angius, 2001). Additionally, the implementation of combined traffic calming measures in three cities in Denmark resulted in an average speed reduction of 8km/h – 10km/h, with a greater reduction in the zones outside the urban areas and a respective speed variation decrease (Herrstedt, 1992).

5.5.2 Safety effects

Several studies have dealt with the assessment of area-wide **traffic calming** schemes (Table 5.10). Elvik and Vaa (2004) summarise the results of several studies and report significant safety effects in terms of injury road accidents, ranging from around 15% in the entire selected area to around 25% - 30% on the residential roads of the selected area. On the main roads forming the boundaries for the selected area, accidents reduction accounts for around 10% (8%-11%). Studies, for which traffic counts are also available, reveal that part of this reduction in the number of accidents in residential streets is due to the reduced traffic (a decrease of approximately 20%-30%), whereas the respective reduction on the main streets can mainly be attributed to the reduced accident rate.

According to another study of Elvik (2001), who performed meta-analysis of safety effects associated to area-wide traffic calming measures, accidents resulting in material damage only are reduced by nearly 20% especially in local streets. More specifically, in the following Table 5.9 the results of evaluation studies by study design and type of road are presented.

Table 5.9. Results of traffic calming evaluation studies by study design and type of road (% change in the number of injury accidents)

Type of road	Study design	Validity of design	Validity of design	
			Best estimate	95% CI (§)
Whole area	Before-and-after, matched comparison group	↑ Acceptable	-12	(-21; -1)
	Before-and-after, general comparison group, and data on traffic volume		-15	(-24; -4)
	Before-and-after, general comparison group, no data on traffic volume		-14	(-19; -8)
	Simple before-and-after, data on traffic volume		-28	(-47; -1)
	Simple before-and-after	↓ Inadequate	-36	(-53; -12)
Main roads	Before-and-after, matched comparison group	↑ Acceptable	-7	(-16; +4)
	Before-and-after, general comparison group, and data on traffic volume		-11	(-21; +0)
	Before-and-after, general comparison group, no data on traffic volume		-7	(-14; +1)
	Simple before-and-after, data on traffic volume		-25	(-47; +6)
	Simple before-and-after	↓ Inadequate	-41	(-80; +68)
Local roads	Before-and-after, matched comparison group	↑ Acceptable	-24	(-44; +3)
	Before-and-after, general comparison group, and data on traffic volume		-34	(-51; -10)
	Before-and-after, general comparison group, no data on traffic volume		-38	(-50; -24)
	Simple before-and-after, data on traffic volume		-32	(-66; +35)
	Simple before-and-after	↓ Inadequate	-10	(-78; +271)

(§) 95% CI = 95% confidence interval

Source: Elvik, 2001

Christensen (2004) applying techniques for meta-regression analysis on existing studies, generated estimates of the effects of traffic calming based on coefficients describing study design and the decade a study was reported. The estimates refer to before-after studies employing a matched comparison group and published after 1990. Christensen found an accident reduction in all the study design and decade groupings that were specified.

Bunn et al. (2004) performed a meta-analysis of area-wide traffic calming projects, including only before-and-after studies that employed a comparison group and estimated a reduction of 37% in fatal accidents, 11% in injury accidents and 5% in all accidents, with the last category likely to consist mostly of material damage only accidents. For pedestrian accidents, Bunn et al. did not find an effect of area-wide traffic calming.

In the three Danish cities, the road safety effect was evaluated on the basis of a before-and-after analysis of accidents recorded by the police and a detailed analysis based on police reports supplemented by inspection of the accident sites in the case of those accidents occurring after implementation. The analysis included a 5-year pre conversion period and a 3-year post conversion period. In Vinderup, there has been a significant reduction (50%, from 13 accidents to 6) in the number of accidents. The number of casualties was also reduced to one-third. The pattern of accidents has changed since as the number of parking accidents was reduced. In Ugerlose, the number of accidents involving personal injury has gone down considerably, while the number of minor accidents involving vehicles driving into sign poles increased (Herrstedt, 1992).

According to a study in three municipalities in Israel regarding the installation of speed-humps on 94 local roads, a 40% reduction in all injury accidents was achieved (Hakkert et al., 2002), whereas in a similar study in Greece, in which the implementation of residential zones (woonerfs) and the installation of speed-humps in one direction, one lane streets in a broad municipal area took place, the average safety effect was a 38% reduction in the total number of injury accidents (Yannis et al., 2005).

According to data collected for Ireland by a questionnaire based survey focusing on the results of specific surveys on infrastructure related road safety measures in the various EU countries, the implementation of a combination of traffic calming measures resulted in significant safety effects. More specifically, 66 sites were treated in total and a reduction of 23% in the overall number of road accidents was observed. Additionally, a reduction of 50% in the number of fatalities, a decrease by 40% and 9% in the number of serious and minor injuries respectively was recorded. Road safety experts from most European countries representing different areas of the European Union filled in the questionnaire, so that specific results of existing studies could be obtained. This survey took place in the framework of the activities of the O7 Task Group of the Road Safety Group of the Conference of European Directors of Roads (CEDR, Questionnaire 2).

Table 5.10. Safety effects of traffic calming related investments

Source	Measure			Description	Country / Region	Road network				Evaluation period	Evaluation method		Safety effect (%)				
	Area-wide traffic calming	Speed humps	Residential zones (woonerfs)			Whole area	Local roads	Main roads	Number of sites		meta-analysis	before/after (control group)	Best estimate	95% conf.int.	fatal accidents	injury accidents	Material damage only accidents
CEDR (Questionnaire 2)	•			Combination of improvements*	Ireland						•	-50	-	•			
CEDR (Questionnaire 2)	•			Combination of improvements*	Ireland						•	-9;-40	-		•		
Bunn et al., 2004	•			Combination of improvements		•					•	-37	-	•			
Bunn et al., 2004	•			Combination of improvements		•					•	-11	-		•		
Bunn et al., 2004	•			Combination of improvements		•					•	-5	-			•	
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS	•					•	-15	(-17;-12)		•		
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS	•					•	-15	(-19;-12)			•	
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS		•				•	-24	(-29;-18)		•		
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS			•			•	-29	(-35;-22)			•	
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS				•		•	-8	(-12;-5)		•		
Elvik and Vaa, 2004	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS				•		•	-11	(-16;-6)			•	
Elvik, 2001	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS	•					•	-15	(-19;-10)		•		
Elvik, 2001	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS		•				•	-34	(-43;-23)		•		
Elvik, 2001	•			Combination of improvements**	Nordic countries, NL, GB, DE, AUS			•			•	-8	(-13;-2)		•		
Herrstedt, 1992	•			Combination of improvements**	Denmark	•			1 city	8 years	•	-50	-		•		
Hakkert et al., 2002		•		installation of speed humps	Israel		•		94 sites in 3 cities	1991-1999	•	-40	(-83;-44)		•		
Yannis et al., 2005		•	•	speed humps and woonerfs	Greece	•	•		21 sites	1991-1999	•	-38	(-106;-36)		•		

* junction improvements, traffic calming, safety barrier, road markings including road studs, surfacing, warning signage and improving sight distance

** traffic signs, speed-humps, woonerfs, one-way traffic, improvement of main roads (parking bans, bus stops, traffic signals, etc.)

s.s: statistically significant

Note: A negative safety effect corresponds to a reduction of accidents

5.5.3 Other effects

Noise levels are usually reduced in residential roads of traffic-calmed areas. According to a Danish study (Herrstedt, 1992) in three cities where area-wide traffic calming measures were implemented, noise measurements inside the town showed that noise has been reduced slightly. However, at the rumble strips noise had increased, the extent depending on the material used. As noise from the rumble strips contains a significant amount of pulsating sounds, this noise is more of a nuisance to the human ear than a constant sound or a sound that varies slowly. Decrease in noise levels between 3dBA - 6dBA due to traffic calming measures have also been observed in a number of areas in Norway, with the exception of some main streets, in which the noise level slightly increased due to increased traffic (Elvik, Vaa, 2004). **Vibrations** associated with vehicles (especially Heavy Goods Vehicles) travelling over speed humps should also be considered.

As regards **air pollution**, important improvements can be observed, especially on local roads; the effect strongly depends on the reduction of traffic. However, part of the effect may be balanced by the fact that lower speeds and increased idling results in increased emissions. According to studies of Hoglund (1995), Webster (1993) and Zuger and Blessing (1995), the reduction of the vehicle's mean speed in areas where speed humps are installed results to significantly increased CO, CO₂ and NO_x emissions. In Denmark the quantities of lead, carbon monoxide, and nitrogen dioxide were studied before and after the traffic calming implementation in three cities and according to Herrstedt (1992), air pollution remained unchanged or slightly reduced in the central part of the cities, while lead concentrations dropped on the edges of the town. However, lead pollution increased at the newly established roundabouts, due to cars accelerating out of the roundabouts. It is also noted that negative effects on the main roads, which accommodate the traffic after the restrictions, usually accompany the positive environmental effects on residential roads and traffic volumes can be increased by 1% - 5% (Elvik, Vaa, 2004).

Traffic calming has generally a negative effect on **mobility** (i.e. increased travel time), due to the through-traffic restrictions and the speed reduction. According to Herrstedt (1992) there is a mean delay of 7sec/km - 10 sec/km at the travel time, definitively depending on the type and extent of the implemented measures. The driving time on selected routes in and out of the traffic calming areas also shows a small increase, probably because there are fewer access points in such areas. Measurement of the gaps of time between cars on the major highways shows that some motorists drive with a smaller gap than before, but the necessary distance is still being kept with an acceptable safety margin.

The inhabitants of areas, where traffic-calming measures have been implemented, are usually very positive in their assessment of the area. They clearly indicate that it has become more appealing and the number of vehicles and their speed has become more acceptable. It should be also noted that the drivers, as a result of the time dis-benefit involved in using these routes, sometimes face traffic-calming schemes with limited acceptability. However, the number of pedestrians and cyclists crossing traffic calming areas increases, as they are feeling more secure. In some cities of Denmark, the number of such road users crossing has increased by more than 60%, while the respective number along the road has increased by 15%. Thus, more pedestrians and more cyclists have ventured out onto the road, they are crossing more frequently than before and additional social benefits can also be recorded for the areas (i.e. increased buying pattern, etc.).

5.5.4 Costs

The **costs** of area-wide traffic calming schemes vary significantly according to the type of traffic engineering measures implemented and the extent of the treatment area. On the other hand, implementation of lower cost traffic calming measures such as speed humps is possible. Maintenance costs should also be included into the implementation cost calculations. On the basis of a survey of several sources, Elvik estimates the average cost of a small area-wide traffic calming to around 250,000 € with annual maintenance costs of around 13,000 €.

In Denmark, the introduction costs for the three pilot cities amount to 1,350,000 € per town. In Cagliari (Italy), the installation of speed humps was low, accounting approximately 700 € per unit for a two 3.50m lane street.

In Greece, the implementation cost of a combination of traffic calming measures (49 speed humps and 100.000m² residential areas) in 21 one-lane, one-way local streets, accounted for approximately 3.4 million € (at 1999 prices), whereas in Israel, the installation of speed humps accounted between 670€ - 1,350€ per unit (at 2000 prices).

In Ireland, the implementation cost of a combination of various traffic calming measures accounted for 1,300,000€.

The costs of accidents analysis, inspections and other activities related to planning, should be added to the implementation costs; however, these costs are not known.

5.5.5 Cost-benefit (B/C) ratio

The results of existing studies indicate that a **marginal to satisfactory cost-effectiveness** (ROSEBUD, 2005, Elvik, Vaa, 2004) generally characterizes traffic-calming schemes. The facts that the traffic engineering measures are relatively low-cost, together with the important safety effect to be expected, render this type of intervention to be very cost-effective in the majority of cases. Care should be taken in the incorporation and quantification of (negative) mobility and (positive) environmental effects in the calculations.

In the case of Israel, the calculated cost-benefit ratio varied between 2.0:1 and 4.0:1 and in the calculations, apart from the implementation costs and the accident costs, the costs for the loss of travel time were considered. In the case-study in Greece, the calculated cost-benefit ratio varied between 2.4:1 and 1.9:1 depending on whether the time lost was considered apart from the implementation and the accident costs.

In Ireland, according to data collected through the Questionnaire 2 of CEDR, the calculated cost-benefit ratio concerning all accidents accounted for 1.94:1 and the respective one for the fatalities 3.68:1.

5.5.6 Strengths, weaknesses and implementation barriers

The above analysis clearly shows that traffic-calming schemes have important safety effects, which, in combination with the relatively low implementation costs, render them cost-effective in the large majority of cases. In particular, many different combinations of measures exist, ranging from implementation of speed humps on individual roads to combinations of various treatments in an area-wide level. As can be seen in Table 5.10, no specific pattern can be identified with respect to safety effects; less extensive treatments do not necessarily bring lower safety effects. Consequently, important safety benefits may be achieved with a relatively low investment.

Therefore, the main **strength** of the investment may be identified in the high, consistent and well-documented safety effects, which appear to be independent of the extensiveness of the implementation of the measures.

Another important strength of traffic calming related investments is their high acceptability; more specifically, these measures are expected to be very welcomed by pedestrians, bicyclists, residents etc.

A possible **implementation barrier** of traffic calming may concern the respective low acceptability of the measures by vehicle drivers.

5.5.7 Summary

The results of the above analysis are summarised in the following Table 5.11:

6 PROPOSAL OF BEST PRACTICE

6.1 Summary of Best Practice

This section summarises the activities and findings of the analysis on the cost-effectiveness of infrastructure related road safety investments and presents a final synthesis and proposal for Best Practice on Cost - Effective Road Safety Infrastructure Investments.

The analysis started from the identification of road safety strategies in the European countries, on the basis of Questionnaire 1 of the CEDR O7 Task Group on Road Safety. It was shown that most European countries set specific quantitative road safety targets and adopt related road safety strategies towards these targets, within the priorities set and the resources available. Within this framework, it was demonstrated that efficiency assessment of road safety investments is considered to be an extremely useful tool in decision making in all countries; in particular, cost-benefit and cost-effectiveness analyses are carried out in several countries, in a more or less systematic way, at national, regional or local level. However, a more widespread use of efficiency assessment tools is in most cases limited by a lack of knowledge, data and appropriate procedures.

Nevertheless, the importance of efficiency assessment in road safety is widely recognised, and the need for more knowledge and best practice examples is stressed by most European countries. More specifically, the needs for best practice recommendations cover the whole range of the efficiency assessment process, from the selection and application of appropriate and standardised methodologies to the interpretation of results and the identification of most efficient investments, especially in case different alternative investments need to be compared and ranked.

On the basis of the above, the first stage of the analysis concerned an exhaustive review of the existing knowledge on the cost-effectiveness of the various road safety investments. In particular, a large number of road safety investments were examined, covering all types of infrastructure, including motorways, rural roads, junctions and urban areas. For each type of infrastructure, all investment areas were examined, including infrastructure design related investments (e.g. road alignment improvements) and infrastructure management related investments (e.g. traffic control). For each one of the investments examined (55 investments in total), a preliminary assessment of safety effects, other effects (namely mobility and environmental effects) and implementation costs was carried out.

These investments were then ranked in relation to their safety effects and implementation costs, under the assumption that investments presenting both higher safety effects and lower implementation costs should be given priority. The results of this ranking showed that there is an important number of promising road safety investments presenting high safety effects and low implementation costs. It was also shown, however, that investments of high safety effects and high implementation costs should also be considered, as they may be proved to be very cost-effective for several road safety infrastructure problems. Obviously, some investments presenting low safety effects but also low implementation costs could also be considered on a case-specific basis, whereas investments presenting low safety effects and high implementation costs are not recommended.

Therefore, the first two groups of road safety investments are those that should be initially exploited for the identification of best practice examples for cost-effective road safety investments. On the basis of the results of the preliminary assessment and the related ranking of investments, five most promising investments were identified and selected for further analysis:

- Roadside treatment (Clear zones, side slopes, safety barriers)
- Speed limits
- Junctions layout (roundabouts, re-alignment, staggering, channelisation)
- Traffic control at junctions (traffic signs, traffic signals)
- Traffic calming schemes

For these five most promising investments, an in-depth analysis was carried out in terms of safety effects, other (mobility, environmental etc.) effects and implementation costs. For this purpose, existing literature was analysed in conjunction with the results of Questionnaire 2 of the CEDR task group O7 (oad safety). The cost-benefit ratio of these investments was subsequently presented and selected as the most advanced and representative measure of their cost-effectiveness. The conditions under which their cost-effectiveness can be maximised or minimised were then described and discussed, resulting in the identification of best practice. Moreover, on the basis of this in-depth analysis, the strengths and weaknesses of each of these most promising investments were presented and possible implementation barriers were identified.

For each investment, an important amount of literature was examined, totaling 155 separate cases, as well as 36 cases reported in the CEDR Questionnaire 2. This allowed for the identification of reliable and statistically significant results on the safety effects and the cost-benefit ratio of the most promising investments. The number of cases analysed within this in-depth analysis are summarised in Table 6.1.

Table 6.1. Sources used in the in-depth analysis of most promising investments

	Number of cases examined	
	International literature	CEDR Questionnaire 2
Roadside treatment	24	7
Speed limits / reduction of operating speed	31	-
Junction layout	60	20
Traffic control at junction	26	7
Traffic calming	14	2
Total	155	36

Table 6.2 summarises the findings with respect to the main components of the cost-effectiveness estimation procedure i.e. safety effects, implementation costs and cost-benefit ratio. It is noted that only statistically significant results were taken into account in this in-depth analysis, in order to minimise the degree of uncertainty in the conclusions.

Roadside treatments in particular have very positive safety effects and no inconsistency or particularity in their implementation that might compromise these effects. However, given that certain treatments present relatively high implementation costs, they are not always cost-effective. This is the case with clear zones and side slopes treatments. Clear zones in particular present relatively high implementation costs. However, the maximum safety effect presented in Table 6.2 may be further increased and may reach a reduction of as much as 95% when this type of treatment is combined with other roadside treatments such as safety barriers.

As regards side slopes, there is a tendency according to which, the steeper the initial slope before treatment, the higher the safety effect observed after treatment; more specifically, the minimum safety effect concerns flattening from 1:4 to 1:6, and the maximum safety effects concerns flattening from 1:3 to 1:4.

Table 6.2. Cost-effectiveness of the most promising road safety infrastructure investments

Investment	Sub-investment	Safety effect (%) *		Implementation cost (€)		Benefit / Cost ratio	
		Min	Max	Min	Max	Min	Max
Roadside treatment	Clear zones	-23		<i>n/a</i>	<i>n/a</i>	< 1:1	<i>n/a</i>
	Side slopes	-22	-42	<i>n/a</i>	<i>n/a</i>	< 1:1	<i>n/a</i>
	Safety barriers	-30	-47	130,000 per km	220,000 per km	8.7:1	32:1
Speed limits / reduction of operating speed	Introducing speed limits	-22		300 per km		> 1:1	<i>n/a</i>
	Reducing speed limits	-9	-67	300 per km		> 1:1	<i>n/a</i>
Junctions layout	Roundabouts	-11	-88	450,000 per junc.	1,300,000 per junc.	2:1	3:1
	Redesigning junctions	-17	-50	1,100,000 per junc.	<i>n/a</i>	3:1	
	Channelisation	+16	-57	65,000 per junc.	1,650,000 per junc.	< 1:1	2.5:1
Traffic control at junctions	STOP signs	-19	-45	250 per sign	700 per sign	< 1:1	6.8:1
	Introducing traffic signals	-15	-36	50,000 per junc.	300,000 per junc.	< 1:1	8:1
	Upgrading traffic signals	+60	-37	<i>n/a</i>	<i>n/a</i>	< 1:1	8.6:1
Traffic calming	Area-wide traffic calming	-8	-50	1,300,000	3,000,000	2:1	4:1

* on target injury accidents

n/a: not available

Note: A negative safety effect corresponds to a reduction of accidents

On the other hand, all types of safety barriers are very cost-effective, especially when they are implemented along embankments on rural roads. Obviously, not all safety barrier types of all materials have the same safety effect, especially when their relative effects on certain specific groups of road users (e.g. motorcyclists, heavy goods vehicles) is taken into consideration. In general, safety barriers that meet the EN 1317 standard are recommended. It is also noted that safety barriers may not be a top-priority treatment for roadside obstacles in all countries.

Although no specific quantitative results were identified, speed limit-related interventions ranging from changes in national traffic rules to local interventions are always expected to be cost-effective, due to the low implementation costs, which mainly involve signposting. Important and consistent safety effects which indicate that raising a speed limit always increases accidents and lowering a speed limit always reduces accidents, were recorded. The maximum safety effect of lowering speed limits is achieved when the initial speed limit is higher than 100 km/h on interurban or rural roads, and when the initial speed limit is 60 km/h or higher in urban areas. It should be emphasised that the effectiveness of speed limit-related interventions largely depends on enforcement.

The relatively high implementation cost of some junction layout treatments does not compromise their cost-effectiveness. Very satisfactory cost-benefit ratios were calculated in the large majority of such cases. However, specific cases where the safety effects may be significantly reduced, or even eliminated, were identified. An interesting related example concerns channelisation, which may have negative safety effects when applied to T-junctions, possibly due to an increase in travel speeds on the minor road. On the other hand, channelisation always has positive effects when applied to 4-leg junctions, and it appears that the more extensive the channelisation (e.g. full physical), the greater the safety effect that is noted.

Redesigning junctions covers a number of interventions, all of which involve increased costs (changing the junction angle, reducing gradients on approach, increasing sight triangles). However, the safety effects are positive and in most cases, satisfactory cost-benefit ratios are achieved. Minimum safety effects result from the reduction of gradients on approach, whereas maximum safety effects correlate with junction angle treatments. Moreover, there is some uncertainty regarding some aspects of sight triangle treatments, and it is recommended that these are carefully examined on a case-specific basis.

Finally, replacing junctions by roundabouts is associated with consistently positive safety effects and satisfactory cost-effectiveness, with safety effects being minimised for signalised T-junctions and maximised for uncontrolled or stop-controlled 4-leg junctions.

A similar pattern can be identified in the category of treatments relating to traffic control at junction-related treatments, and specifically in the case of the introduction of 'stop' signs at uncontrolled junctions. In this situation, the minimum safety effect is gained in the case of one-way stops at T-junctions, whereas the maximum safety effect is achieved in the case of all-way stops at 4-leg junctions. In all such cases, a positive cost-benefit ratio is expected, due to very low implementation costs (i.e. for simple signposting). However, it is noted that the results may be quite different as regards the implementation of 'yield' signs at uncontrolled junctions: here, the safety effects are less consistent and less statistically significant, therefore no reliable conclusions can be drawn.

The maximum safety effect achieved by introducing traffic signals at junctions is again associated with 4-leg junction treatments. Important safety effects are also achieved by upgrading traffic signals. However, this is so only when the upgrade leads to more efficient accommodation or separation of traffic flows. More specifically, the maximum safety effects of traffic signal upgrades result from the re-timing of traffic signals, the introduction of separate pedestrian phases, or the introduction of separate left-turn phases. It is emphasised that any modification in traffic signal operation that involves the introduction of mixed phases (e.g. mixed pedestrian phase, right-turn permission during red signal) may result in a significant increase in road accidents. Nowadays, in most countries, such investments are rarely applied. In any case, the positive safety effects noted above are associated with very satisfactory cost-benefit ratios.

It is very interesting to note that traffic-calming schemes always appear to have positive safety effects and satisfactory cost-effectiveness, regardless of the type or the extent of these treatments. This is particularly impressive when considering that traffic-calming schemes may range from simple speed humps on a few roads (at low cost), to area-wide combinations of several treatments (with obviously higher costs). Nevertheless, no pattern was found to justify the conclusion that more extensive treatments have higher safety effects or are more cost-effective: therefore traffic calming schemes can be considered a priority safety investment for urban and residential areas.

Based on the outcomes of the analysis, it is obvious that the overall cost-effectiveness of a road safety infrastructure investment is not always in direct correlation with the safety effect. Several interesting results are demonstrated in Table 6.1. Roundabouts have very high safety effects, which are not directly reflected in the cost-benefit ratios available. On the other hand, the cost-benefit ratios of traffic signals are higher than those of roundabouts, although the safety effects of traffic signals are much less impressive. In this case, a comparison of cost-benefit ratios only might lead the less-informed reader to the misleading conclusion that traffic signals are more efficient than roundabouts, whereas what is indicated is that they are simply more cost-effective. Consequently, it is recommended that cost-benefit ratios and safety effects are always examined in conjunction with each other in order to identify the optimum solution for a specific road safety problem in specific conditions and with specific objectives.

It should be stressed that the above ranges of results can by no means be considered to be applicable to every application of these investments. Although the cases examined were relatively representative and the results quite consistent, it is always possible that the particularities of setting, context, and implementation features of a specific case may produce results with varying degrees of difference.

Furthermore, in the present Synthesis, the five most promising investments were examined individually. However, important interrelations exist among these most promising investments. For instance, roadside treatments, junction layout treatments, and speed limit-related interventions could be considered a main set of most promising investments on interurban and rural roads. On the other hand, traffic calming, junction layout, and traffic control at junctions may be considered a main set of most promising investments in urban areas. In any case, additional investments that are not included among the five most promising investments may also be necessary.

In practice, there may rarely be a single answer to a specific road safety problem. On the contrary, a set of infrastructure interventions may be required. In any case, efficient planning and implementation of an investment requires that all related parameters are examined and dealt with. Accordingly, the safety effects of the most promising investments cannot be guaranteed, especially if additional factors need to be examined before implementation.

The knowledge obtained from this exhaustive review should prove very useful in the identification of the most cost-effective investments for different road safety problems and in the preliminary selection of the main characteristics of such investments. However, thorough analysis on a case-specific basis is always necessary in order to optimise the effects of an investment in different countries or areas, by taking into account the extent of the implementation, the implementation period, and specific national or local requirements. Furthermore, it is necessary to ensure that such analyses are carried out in accordance with recognised standard methodologies.

Cost-benefit and cost-efficiency analyses are considered to be the most important tools in the hands of decision-makers for the economic appraisal of various road safety measures. The extensive review of the most promising infrastructure-related road safety measures revealed the important potential of these evaluation techniques in the overall decision-making process worldwide. Several useful conclusions concerning the basic components required for the execution of efficiency assessment have been derived from the experience gained in using these evaluation techniques.

It is important to emphasise, however, that the above ranges of results may not apply to every application of these investments. It is always possible that particularities of the setting, context, and implementation features may bring more or less different results in a specific case. Given that each of the investments analysed presents its own particularities, strengths, and weaknesses, no generalised rules can be formulated for decision-making. For this reason, the following section presents an outline of the basic parameters that need to be taken into account for a most efficient integration of cost-effectiveness in road safety decision making. Moreover, the main issues that need to be addressed within the selection and implementation of cost-effective road safety investments are summarised.

6.2 Discussion

6.2.1 Applied evaluation techniques

Only cost-benefit analysis was applied in all case studies reviewed in this Synthesis. In some studies no investment alternatives were considered and the implementation of a specific investment was assessed against no safety investment at all. All other steps of the cost-benefit analysis evaluation procedure, i.e. consideration of safety effects and side effects (on mobility and environment), presenting all effects in monetary terms, estimating implementation costs, calculation of present values of costs and benefits and of efficiency measure (cost-benefit ratio), were applied in the majority of the studies; any exceptions were mainly due to lack of data.

During the estimation of the safety effects of the measures, emphasis was put on the application of correct safety evaluation and with reference to the economic evaluation, typical scenarios adopted can be characterised as "conservative" or "best estimate", although they were based on different approaches in each case.

Summarising the performance of the reviewed studies, several conclusions can be drawn, indicating common technical problems which might occur during the cost-benefit analysis evaluations. These are mainly related to the correct application of the techniques, identification of ways for validating the statistical significance of the evaluation results, the proper selection of side-effects to be considered along with safety effects and also the correct distinction between the implementation costs and negative side-effects of the measure.

In cases where a number of impacts are combined in the evaluation of a measure, a distinction should be made between the implementation costs and negative benefits of the measure. Implementation costs are the social costs of all means of production (labour and capital) that are employed to implement the measure, whereas the benefits include all effects which stem from the measure's application. Some benefits may be negative, i.e. increased travel time and in such cases, their values are subtracted from the total benefits.

The applicable techniques can be found in many literature sources and it is common acknowledgement that a distribution of a brief guide on standardised techniques for the evaluation of safety effects would be helpful for safety practitioners and particularly, for the improvement of quality of the efficiency assessment studies.

6.2.2 The efficiency assessment components: data and values

Accident data is usually rather easily accessible. The valuations of road accident injury costs are usually provided by recently published evaluation studies, however, it is difficult to attain costs of road safety measures. In the cases of infrastructure improvements, the investments are in most cases paid from the public sector, therefore it frequently appears difficult to determine the total values of these costs. Consultations with the responsible decision-makers and analysis of valuations from similar studies may serve as the appropriate sources of values in such cases.

To stimulate the application of more uniform and well-based values of safety effects, it would be useful to establish a database with typical values of the effects, based on international experience. Such a database might be open to a European network of experts and provide for general values of safety effects on initial steps of cost-benefit/cost-effectiveness analyses, as well as assist in judging the local effects observed.

Lack of models for evaluating side-effects associated with the safety measure (i.e. changes in air pollution, noise level, travel time or fuel consumption) and sometimes lack of local valuations of these effects, deter their consideration by the efficiency assessment studies. This constrain can be tackled by a systematic accumulation of recommended values and solutions, depending on safety measures considered, within the guidelines for the efficiency assessment performance.

6.2.3 Role of barriers to the evaluation of road safety measures

In the evaluation of infrastructure related road safety measures there are relative barriers, of institutional or technical nature, which may significantly influence the cases' performance. Technical barriers such as typical problems with the evaluation techniques or lacking of data, are generally overcome by the evaluation studies and in some cases, thoroughly based statistical models are developed to ascertain the lacking values of the effects.

Lack of obligatory procedure for the performance of cost-benefit evaluations of safety effects is also acknowledged as a major institutional barrier for the application of the efficiency assessment on road safety measures. However, in many cases the cost-benefit analysis results emphasise the accident reduction effects and the economic savings associated with the measures' application. As a result, the decision-makers are interested in the distribution of the efficiency assessment outcomes and in further performance of the analyses.

As to the barriers for implementation of safety measures, which are evaluated by some of the studies and found effective, different forms of these can be identified. The wide application of the infrastructure related measure is frequently limited due to lack of finance, high costs, and other economic reasons. Sometimes, safety reasons may conflict with other considerations (i.e. environmental issues) and in other cases lack of acceptance by the general public deters the decision-makers from the measure's promotion. However, in several cases the cost-benefit assessment results can highlight the expected benefits of the measures and in this way, contribute to the acceptance of the measure by the decision-makers.

6.2.4 Role of efficiency assessment in decision-making

Efficiency assessment is often an important part of the preparation of national, regional or local road safety plans. At the initial stage of evaluation, safety effects are usually unknown and in order to influence any decision making process, the efficiency assessment studies have to be prepared ex-ante, using impact data from similar measures application. This stresses the need for availability and accessibility of evaluation studies on road safety measures, as well as dissemination of efficiency assessment results on an international basis.

At the local level, the application of a road safety measure does not only depend on its economic profile but also on subjective judgment. In case a program of efficient infrastructure related road safety measures is developed at the national level but executed at regional or local level, benefits estimated at the national level may not be visible at the local level, where costs and local political interests dominate the decision makers' perspective. During the preparation of efficiency assessment studies within such an environment, the financial benefits need to be explained, considering the level of future decision making in the best possible way.

Moreover, there are cases where decision-making at local level is influenced by personal experiences, highlighting the conflict between traditional arguments used in decision making and efficiency assessment as an instrument to be promoted. Decisions at the local level involve both global and local interests, thus in order to present any results it is important to fit the arguments to the level of decision-makers.

To safeguard the intentions of the national safety programs, the arguments need to include an appropriate presentation for the promotion of the original intentions at the regional or local level. It should also be mentioned that local decision makers in charge of road safety decisions believe that other than casualties (i.e. mobility costs, time use, and environmental costs) can hardly be used in local decision-making.

In countries where the safety budget is centralised and projects are mostly financed by the government, the requirement of a cost-benefit analysis of safety measures may be distributed by stating it as a condition for the application of projects coming from the central budget.

6.3 Conclusion

This Synthesis on cost-effective infrastructure related road safety investments illustrated best practice in Europe and worldwide, which is essential as it may assist to better understand the way that road safety improvements have been achieved by successfully applying single infrastructural road safety measures or integrated approaches that have proved to be effective. Based on the analysis of relevant literature, the results achieved under similar circumstances can be used to forecast effects of measures to be implemented and thus, specific guidelines can be formulated for ensuring the efficient application of road safety policies.

Additionally, some fundamental principles on the successful application of efficiency evaluation techniques on infrastructure related investments were noted, exploiting the experience attained through the extensive relevant literature review of several case-studies worldwide. The efficiency assessment components, the barriers to the assessment procedure, as well as the role of efficiency assessment in decision making were highlighted, as they all consist of important factors that should be considered when evaluating the efficiency of any road safety measure.

It should be noted though that no "magic recipes" or panaceas exist when it comes to the final decision between infrastructure related road safety measures. Their cost-effectiveness differs among the country in which they are implemented, the implementation period, the extent of the implemented measure, but also the overall road safety level of the country. Especially as regards the safety effects derived by the reviewed studies for each measure, these can be differentiated by the specific characteristics of the country in which they are implemented. Moreover, the implementation costs for infrastructure related investments, which are usually high comparing to other road safety measures (i.e. intensification of enforcement, road safety campaigns, etc) may vary significantly among the countries, especially when a combination of measures is proposed.

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