Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

Best Practice for Cost-Effective Road Safety Infrastructure Investments

Summary Report

The full report is available on www.cedr.eu Publications 2008

April 2008

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Edited and published by: CEDR's Secretariat General

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1. INTRODUCTION

1.2 Scope and objectives

Economic appraisal of road safety measures is considered a very important tool in the hands of decision-makers. Within task group O7, an ad hoc group set up by the road safety group of the **C**onference of **E**uropean **D**irectors of **R**oads (**CEDR**), an effort to understand, identify, and disseminate best practice to ensure cost-effectiveness in road safety investments has been initiated. This initiative is part of a broader strategic plan which defines the priorities that the organisation has set for the four-year 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 Figure 1.1 below.

A **review of selected reference documents** was carried out, including the two questionnaires issued by task group O7 (road safety), a number of reports from European and national research projects (ROSEBUD, PROMISING, VESIPO, etc.), together with a set of key publications (*Handbook of Road Safety Measures* by Elvik and Vaa, the PIARC *Road Safety Manual*, the FHWA *Highway Safety Manual*, etc.). Moreover, a review of a significant number of other scientific papers, reports, and national studies was carried out. An exhaustive list of road safety infrastructure investments was initially compiled from these sources of information, and individual investments were classified according to the infrastructure investment area and the type of investment. Thereafter, individual **investments were analysed on the basis of safety effects, implementation costs, other (non-safety) effects, and cost-effectiveness**.

Figure 1.1 *Methodology flow chart*

In particular, a large number of road safety investments covering all types of infrastructure—including motorways, rural roads, junctions, and urban areas—were examined. For each type of infrastructure, all investment areas were examined, including design-related infrastructure investments (e.g. road alignment improvements) and management-related infrastructure investments (e.g. traffic control).

These investments were then ranked in relation to their safety effects and implementation costs, under the assumption that investments presenting greater safety effects and lower implementation costs should be given priority. On the basis of the results of this preliminary assessment and the related ranking of investments, **a set of five most promising investments was selected**. For these five most promising investments, an in-depth analysis of safety effects, other (mobility, environmental, etc.) effects, and implementation costs was carried out. For this purpose, existing literature was analysed, in conjunction with the results of questionnaire 2 issued by the CEDR task group O7 (road safety).

Subsequently, the cost-benefit ratios of these investments were determined and selected as the most advanced and representative measure of cost-effectiveness. The conditions under which the cost-effectiveness of the selected investments 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 and potential barriers to their implementation were identified. The results permitted an **identification of best practice for cost-effective road safety infrastructure investments**.

2. COST-EFFECTIVENESS ASSESSMENT OF ROAD SAFETY INVESTMENTS

2.1 Review of road safety strategies in 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, 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 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 for road safety investments

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.

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.

3. REVIEW AND ASSESSMENT OF ROAD SAFETY INVESTMENTS

3.1 Summary of investments

In the previous chapter, the need for quantitative results from efficiency assessments 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 has 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):

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

Motorways
- development of motorways
- development of interchanges

Rural roads
- horizontal curvature treatment (increasing curve radii, introduction of transition curves, reducing the frequency of curves, superelevation treatment)
- vertical curvature treatment (reducing gradient, reducing the frequency of 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)
- road/rail crossings treatment (introduction of road/rail grade crossings, protection of road/rail level crossings)

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)

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. The detailed analysis of the above investments is included in Chapter 3 of the CEDR final report, *Best practice for cost-effective road safety infrastructure investments*. The results are summarised in Table 3.1 below. In particular, a list of the **road safety investments examined** is presented (it is noted that general investments e.g. road safety audits, are not included in this analysis). 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 were analysed; these fall within 18 **investment areas**, each one belonging to one or more of 4 infrastructure categories. The following analysis focuses on the individual investment level. In particular, it is specified in Table 3.1 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 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.

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 Investissments examined	Implementation Cost	Safety effect
10	Low	High
21	High	High
3	Low	High/low
5	High	High/lLow
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 3.1 *Summary of investments*

	Investment areas	Investments	Implementation cost		Safety effect		Intervention area			Acceptability	
			High	Low	High	Low	Bend	Junction	Section	High	Low
Motor-ways	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			•	
	Vertical curvature treatment	Reducing gradient	•		•				x	•	
		Reducing the frequency of curves	•			•	x			•	
		Improvement of sight distances	•		•		x	x	x	•	
	Cross-section treatment	Increasing the number of lanes	•		•	•	x		x	•	
		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	•	
	Roadside treatment	Flattening side slopes	•		•		x		x	•	
		Establishment of clear zones	•		•		x		x	•	
		Implementation of safety barriers		•	•		x		x	•	
		Replacing safety barriers to meet the EN 1317 standard		•	•		x		x	•	
	Speed limits	Changing from unrestricted speed to speed limit		•	•		x	x	x		•
		Lowering existing speed limit		•	•		x	x	x		•
		Creation of speed transition zones	•	•	•			x	x	•	•
	Traffic control and operational elements	Traffic signs (regulatory)		•	•			x		•	
		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		•
	e-Safety systems	Navigation routing		•		•	x	x	x	•	
		Weather info VMS	•		•			x	x	•	
		Congestion info VMS	•		•			x	x	•	
		Individual info VMS	•		•	•		x	x		•
		Vision Enhancement Systems	•		•		x	x	x	•	
	Road surface treatment	Ordinary resurfacing	•		•***		x	x	x	•	
		Improving road surface evenness	•			•	x	x	x	•	
		Improving road surface friction	•		•***		x	x	x	•	
		Improving road surface brightness	•			•	x	x	x	•	
	Lighting treatment	Implementation of artificial lighting		•	•***	•***	x	x	x	•	
		Improving existing lighting		•	•***	•***	x	x	x	•	
	Rail / road crossings treatment	Introduction of rail/road grade crossings	•		•			x		•	
		Protection of rail/road level crossings		•	•			x		•	
Junctions	Construction of roundabouts	Development of roundabouts	•		•			x		•	
	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 from country to country as they depend on national/local conditions.

3.2 Identification of the 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 a high safety effect 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 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.

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***Table 3.2** 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 3.2, individual investments are **classified in four categories**, based on combinations of their rankings for safety effects and implementation costs (high or low).

In Table 3.2, 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 3.2 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 3.2. 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 3.2.

In particular, the suggested **most promising road safety investments** in terms of cost-effectiveness mainly fall within five specific investment areas, summarised in Table 3.3 below.

Table 3.3 *Selection of the most promising investments for further analysis*

- **Roadside treatments**
  (clear zones, safety barriers)
- **Speed limits/lowering of operating speed**
- **Junctions layout**
  (roundabout, 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.

4. IN-DEPTH ANALYSIS OF THE MOST PROMISING ROAD SAFETY INVESTMENTS

In the CEDR final report, *Best practice for cost-effective road safety infrastructure investments*, an **in-depth analysis of the five most promising investments** was carried out. For each investment, a considerable amount of literature, describing a total of 155 separate cases, was examined, in conjunction with 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 ratios of the most promising investments. The types and number of cases examined in this in-depth analysis are summarised in Table 4.1 below.

The results were further compared among different countries and different road networks (interurban, rural, urban). In the following sections, **summary results** are presented for the five most promising investments. It is noted that only the overall ranges of effects are reported (e.g. minimum and maximum safety effects, implementation costs and cost-benefit ratios). Given the fact that these ranges are often broad, the reader is encouraged to consult the full version of the final report for more detailed information and specific examples from different countries.

Table 4.1 *Sources used in the in-depth analysis of the most promising investments*

	Number of cases examined	
	International literature	CEDR Questionnaire 2
Roadside treatments	24	7
Speed limits	31	-
Junction layout	60	20
Traffic control at junctions	26	7
Traffic calming	14	2
Total	**155**	**36**

4.1 Roadside treatment

The results concerning roadside treatments are summarised in Table 4.2 below.

Table 4.2 *Roadside treatment—summary of findings*

Investment: roadside treatment
Network: mainly interurban / rural
Sub-investments: (not considered separately)

- 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

Maximum safety effect:
● installation or replacement of safety barriers (-47%)
  - especially when combined with other roadside works.

Minimum (or negative) safety effect:
● flattening side slopes (-22%)
  - especially from 1:4 to 1:6 on two-lane undivided roads

Max. C-B ratio*:
● safety barriers, considering only safety effects 32:1

Min. C-B ratio*:
● safety barriers, considering only safety effects 8.7:1

Implementation costs per unit:
● installation of safety barriers € 130,000 – € 220,000 per km, depending on type

Other effects:
● negative effects on environment in some cases (e.g. tree removal)
● slight increase in average speed

Strengths:
- significant safety effects on the number of accidents with casualties, but also on accident severity
- validated cost-effectiveness
- high acceptability by road users

Weaknesses:
- relatively high implementation cost
- side effects on the surrounding environment/landscape
- slight increase in the number of damage-only accidents in some cases

Implementation barriers:
- 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.*

4.2 Speed limits / lowering of operating speed

The results concerning speed limits are summarised in Table 4.3 below.

***Table 4.3** 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

4.3 Junction layout

The results concerning junction layout are summarised in Table 4.4 below.

***Table 4.4** 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 channelisations 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.*

4.4 Traffic control at junctions

The results concerning traffic control at junctions are summarised in Table 4.5 below.

Table 4.5 *Traffic control at junctions—summary of findings*

Investment: traffic control at junctions
Network: rural / urban
Sub-investments:
- 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

4.5 Traffic-calming schemes

The results concerning traffic-calming schemes are summarised in Table 4.6 below.

Table 4.6 *Traffic calming—summary of findings*

Investment: traffic calming
Network: urban areas
Sub-investments:
(not considered separately)
- development of pedestrian streets
- development of residential zones (*woonerfs*)
- introduction of speed humps
- lowering 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

Maximum safety effect:
- ● no specific pattern identified. A single sub-investment and a combination of sub-investments, area-wide implementation or not, can be equally effective (-8% to -50%).

Minimum (or negative) safety effect:
- ● the investments appear to have somewhat lower safety effects when implemented on main roads.

Max. C-B ratio:
- ● traffic calming 2:1 - 4:1

Min. C-B ratio:
- ● when vehicle delays are important > 2:1

Implementation costs per unit:
- ● introduction of speed humps € 700 – 1,350 per unit
- ● area-wide traffic calming € 1'300'000 – 3'000'000 in total

Other effects:
- ● effects on noise, pollution, and mobility

Strengths:
- ● many possible combinations of measures, always significant accident reduction
- ● validated cost-effectiveness
- ● high acceptability by residents, pedestrians, bicyclists, etc.

Weaknesses:
- noise (for rumble strips) and vibrations (for humps)

Implementation barriers:
- low acceptability by drivers

5. PROPOSAL FOR BEST PRACTICE

An **in-depth analysis** of the five most promising investments was carried out in terms of their 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 CEDR task group O7 (road 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 are identified.

Table 5.1 summarises these 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 was found. 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-slope treatments. Clear zones in particular present relatively high implementation costs. However, the maximum safety effect presented in Table 5.1 may be further increased and may reach a reduction of as much as 95 per cent 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 5.1 *Cost-effectiveness of the most promising road safety investments*

Investment	Sub-investment	Safety effect (%) *		Implementation cost (€)		Benefit / Cost ratio	
		Min	Max	Min	Max	Min	Max
Roadside treatment	Clear zones	-23		*n/a*	*n/a*	< 1:1	*n/a*
	Side slopes	-22	-42	*n/a*	*n/a*	< 1:1	*n/a*
	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	*n/a*
	Lowering speed limits	-9	-67	300 per km		> 1:1	*n/a*
Junction 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.	*n/a*	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	*n/a*	*n/a*	< 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 in 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 were recorded which indicate that raising a speed limit, always increases accidents and lowering a speed limit always reduces accidents. 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 5.1. 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.

To summarise, the in-depth analysis revealed the range of safety effects, implementation costs, and eventual cost-effectiveness that can be expected from the most promising investments. Therefore, the existing knowledge was subjected to an exhaustive analysis. As only statistically significant and well-documented results were taken into account in the above synthesis, the degree of uncertainty is minimised. Consequently, these best practice examples could be optimally used as **an overall guide towards a more efficient planning of the investments**.

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**. Thorough analysis on a case-specific basis is always required, as the present synthesis is no more than an organised, comprehensive guide containing all existing information on the cost-effectiveness of road safety infrastructure investments. It aims to support decision-making at both strategic and implementation level. However, it cannot replace case-specific studies, which are essential if the particular conditions of each case are to be taken into account.

Ref: CEDR report 2008/03 TDOperation2008 / CostEffectiveRoadSafetyInvestments

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