Sustainable Surface Transport
SIXTH FRAMEWORK PROGRAMME

rankers
ranking for european road safety

RANKING FOR EUROPEAN ROAD SAFEY
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2.0	02/01/08	First version including catalogue tables
3.0	02/02/08	Draft version of the document
4.0	20/08/08	Final version

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1. Introduction

One of the main objectives of the RANKERS project was to provide a scientific catalogue of road infrastructure based countermeasures ranked according to the relation between their cost and effectiveness. This will help road operators to identify the best solutions for each road safety problem in order to maximize the benefits that can be obtained from the available resources.

This deliverable consolidates, condenses and completes the scientific investigations which have taken place throughout the first three RANKERS Work Packages.

Its ultimate objective is to present a user-friendly catalogue of best-practice engineering measures adapted to a range of accident scenarios investigated by the RANKERS consortium and ranked according to cost – effectiveness criteria.

In doing so, the report will first recall a number of important considerations which have emerged from the theoretical work and field studies carried out within RANKERS.

This deliverable therefore constitutes a common repository of knowledge gained within the project.

2. Road safety and road infrastructure

2.1. State of the art

Single vehicle accidents in Europe represent 35.5% of fatalities in motorways and 27.3% in other roads. This type of accidents implies a close relationship between the driver, the vehicle and the road infrastructure. The latter constitutes one of the key elements as there are no other vehicles involved. Therefore, road infrastructure can contribute to enhance safety levels across Europe. It is hence of paramount importance that road transport networks are designed and built taking into account the safety of motorists in order to minimise the number of fatalities on European roads.

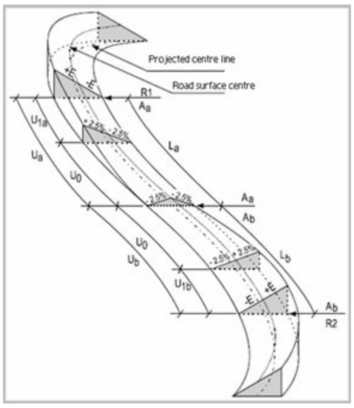
RANKERS partners analysed various aspects relating to the type of accidents taking place on the European road transport network in order to create a Road Safety Index and the Ranking of the remedial measures to be implemented in defective sections, offering a cost-benefit analysis so that public authorities are able to have additional information available when making a choice.

In order to create this catalogue of recommendations it was necessary to gather information over a wide variety of topics which had to be identified early in the projects lifetime. For RANKERS, seven categories were singled out as being the most important to analyse in order to have a catalogue of remedial measures offering the best information possible. These were:

- Accident types on non-urban roads;
- The relationship between road infrastructure, its surface and the accident rate;
- Statistical methods of accident analysis;
- Evaluation of infrastructure improvements;
- Cost-benefit analysis;
- Human behaviour analysis;
- Existing guidelines.

As per accidents occurring in **non-urban roads**, research conducted outlined how a relative majority of these represented runoffs where a single vehicle hit some form of roadside furniture. In fact previous research (cfr. RISER Project) has found that single vehicle runoffs account for around 1/3 of all accidents on this type of road infrastructure, often caused by driver drowsiness. Although single vehicle crashes against roadside furniture (by roadside furniture it is intended any object which is placed on or in the immediate vicinity of the road) were singled out as the most interesting and most recurring type of accidents in non-urban environments, the partners also devoted attention to accidents involving more than one vehicle, most notable rear-end collisions and collisions caused by vehicles changing lanes. The analysis of these types of accidents was of paramount importance for the composition of the catalogue as it enabled the RANKERS partners to ascertain the type of infrastructure measures which would yield the best results in terms of accident mitigation.

Identifying the most frequently occurring types of accidents in non-urban environments was only the first step in the process, which then moved on to ascertaining the role played by road **infrastructure and its surface**, in particular in relation to the accident rates within particular road sections.



Road characteristics, such as friction and roughness and horizontal alignments were the centre of attention in reviewing road infrastructure studies. There was no conflict among research results that curves have higher accident risk and accident risk increase with decreasing curve radii.

Of particular interest were the findings in one country where the risk of accidents in curves was higher for right hand curves than in left hand curves, even when superelevation would support vehicle cornering capabilities. In these conditions it was also noted that the type of accident changed as overtaking accidents increased in right hand curves.

Road surface was also singled out and analysed to evaluate its contribution to the relative danger level of a particular road section. Conclusions of the effect of the road surface were however diverse. Better friction, from the vehicle dynamics point of view, such as gravelled and dry road surface, in fact, resulted in better traffic safety. Environmental factors also played a key role, with drivers much more likely to adopt a more defensive driving attitude when facing adverse meteorological conditions and less grip on the tarmac.

After resurfacing, studies outlined an increase in the overall level of accidents, a factor associated with vehicles moving at higher speeds on resurfaced roads due mainly to a driver perception of a decrease in risk, but also in the smoother vehicle to infrastructure interaction. It was however also noted that resurfaced roads can have a positive impact on road safety due to the additional friction and braking capability on this less degraded infrastructure.

Furthermore the width of lanes was also taken into consideration in the overall analysis on infrastructure, with results confirming that wider lanes are inherently more dangerous than narrower ones. This again was due to the fact that vehicles tend to travel at higher speeds when they are occupying a lane which allows them for more manoeuvring space, stemming from the driver’s perception of a decrease in risk and a false increase in the overall safety levels. Wider lanes are hence to be considered a safety issue which needs to be taken into consideration. Relevant solutions can be readily identified to correct problems arising from road infrastructure problems which were identified in the course of the project, ranging from the very simple and cheap to the very complex and expensive. The catalogue provides hence a guide which can act as an aid to administrators when analysing the type of road accidents within their territory and planning for potential solutions.

Any road-related problem which is not corrected within a short time frame, in fact, will result in an accident taking place and possibly an injury occurring. The presence, for instance, of roadside objects either too close to the road itself or inadequately protected, is a factor which will yield a collision at some point in the future. The possibility and the frequency of accidents potentially occurring within determined segments of road infrastructure can be analysed by using statistical tools able to predict them within a certain level of accuracy.

This statistical analysis was one of the key aspects within RANKERS, as it allowed for a prediction of the level of safety of determined road section, an aspect which plays a vital role in the *Road Safety Index* and something necessary to analyse the effectiveness of the proposed countermeasures.

Determined accidents occurring with a certain frequency translate, in fact, into possible solutions to avoid or mitigate the accidents themselves. Again it is important to stress that unsafe sections of road infrastructure will determine accidents at some point in the future, an aspect that no administration can ignore. Using to their full extent the tools and technological developments available becomes one of the most important aspects that need to be considered. A catalogue offering recommendations on remedial measures becomes an invaluable tool allowing decision makers to have more information on the costs and benefits of potential solutions available to them and implementing the one most suited for their personal needs.

Once the analysis of accident types had been conducted, RANKERS partners proceeded to identifying potential improvements of the infrastructure which would mitigate the effects of an accident. The countermeasure catalogue was hence born, stemming from an analysis of the most significant publications in road safety and road engineering, including public information campaigns and police enforcement as well as the field tests carried out within Work Package 2 (Analysis of Road Safety Infrastructure). Countermeasures range from small roadside improvements to complete road realignments and serve the purpose of providing solutions to problems of safety in road infrastructure. Although possible solutions to road transport safety problems are not themselves an innovation in the field, the ranking of these according to the specific criteria of cost-benefit is something specific to the RANKERS project.

In order to be able to achieve this, however, it was necessary to develop methodologies to correctly evaluate how much a specific countermeasure would cost, something straightforward as manufacturing and installation/maintenance costs are usually known, and also the potential benefits of each specific solution. This last aspect is always more difficult to calculate as a standard methodology had to be identified to assure that all the countermeasures are weighted according to a standard procedure which produces fair and unskewed results.

2.2. Human factors in road design

Driving is a complex task of a dynamic nature subject to temporal constraints and calling for a continuous adjustment to a changing road environment. The driver is required to identify, in time and space, sources of potential danger that could affect his safety on the road. He has to know where, when, how and with what force he must carry out the necessary regulating actions. It is important to analyze how the driver perceives and identifies road situations, changes in them, and the regulating actions they imply.

Driver performance can be evaluated through five parameters: the information received, the interpretation of this information made, the decision taken, the action executed and the vehicle's reaction to it. An important fact is that drivers not only process the visual information but also perceive sensations from the road surface and the vehicle while driving. Therefore, a link between the road environment and the driver behaviour (as well as between driver and vehicle) can be established, and as Sagberg, Hakkert, Larsen, Leden, Schmotzer et al (1999) aimed at mental load can be considered an important intervening variable, considering that an amount of relevant information that exceeds the driver's cognitive (attentional) capacity for information processing can lead to a loss of crucial information, ensuing erroneous decisions and possibly resulting in accidents. Most of researches point out human error is implicated in most of the accidents. Treat, Tumbas, Mc Donald, Shinar, Hume, Mayer et al. (1977) found that human error was the sole cause in 57% of the all accidents and was a contributing factor in over 90%. The question is why do humans make so many driving errors? The answer to this question is in the inherent limitations of human information processing.

A number of environment, road and driver factors are likely to exert some influence on the perception and choice of travel speed. Jennings and Demetsky (1983), for instance, listed 16 road and environment variables they claimed would influence driving behaviour on the road, such as: time of day radius of curvature, lane and road width, shoulder width, intersecting roads or driveways, average speeds of traffic, delineator type and number, weather conditions, roadway grade, length of curve, existing pavement markings, nature of adjacent lane, traffic volume, delineator spacing, sight distance, etc…being the key query how environment might affect driver performance. There have been a great amount of studies which have focused on knowing the influence of road and environment variables affect driving performance.

The first group of researches has been focused on knowing how to improve the **traffic signs recognition** and how to avoid distractions and human errors provoked by them. The objective of the signal display is transmit an unambiguous message to the driver, quickly and clearly, to minimize disturbance with the other users and control task and to allow a sufficient time after recognizing the message to make decision and control action (Allen, Parseghian and Rosenthal,1994).

Traffic signs provide regulatory, warning or guidance information to drivers. As such, effective and timely conveyance of information from traffic signs to drivers can decrease the traffic accidents. The information conveyance depends, in part, on the legibility and recognition of the traffic sign content, which is a function of traffic sign and observer characteristics. The primary traffic sign features that affect night-time legibility and recognition are the background luminance and luminance contrast of the traffic sign, as well as the critical visual detail of the message on the sign. There are many observer characteristics that affect the legibility or recognition performance. However, two key characteristics are the visual acuity and the contrast sensitivity (Schnell, Aktan and Li, 2004).

Drivers' perception processes are very important in understanding the effectiveness of a traffic signal display. Woodson (1987) has identified the following principles that enhance perception and reaction to traffic signal displays: conspicuity, visibility, emphasis, maintainability, legibility, intelligibility and standardization. Recognition of a traffic signal display is a measure of driver's ability to identify the contents or component parts of the traffic signal message and corresponding response. Response is a measure of driver recognition and is equated to how much time it takes for a driver to identify the traffic signal's content. Similarly, comprehension is a measure of well the driver understands the meaning of the traffic control device's message, as intended by its designer. Comprehension of a device can be measured by the number of drivers that correctly understand its intended message within an acceptable response time.

Regarding distraction, most of the studies has been focused on driver distraction by advertising. Visual environment is being more and more complex, with a proliferation of signs, billboards, adverts, shop fronts, and even public art installations, etc.

McMonagle (1952) concluded accidents are correlated with road complexity. Straight roads where traffic can flow easily are safer than congested roads with many intersections, taverns and gas station. This idea has been supported by almost every subsequent study. Staffeld (1953) found out roads which tended to have high-speed traffic, low to medium traffic volume, low complexity (few intersections) and few advertising signs tended to have fewer accidents than roads which did not. Rusch (1951) found that shops and advertising seem to correlate with high accident rates, but didn't make an effort to separate out these variables.

In this line, Neuburger (1963) aimed at there have been a higher of accidents in sections of the highway with a high number of advertising billboards. Ady (1967) was emphatic and concluded that all advertising billboards caused accidents and it was possible that some signs in some situations might cause accidents. After all, some signs are large, others are small, some are brightly lit, etc…Moreover, and it also seems likely that the content of the sign plays a part in how distracting it may be. But these studies have been criticised because they have problems ecological validity, can't prove causation, all this studies are correlational and in all experiments drivers are looking for something, their reaction times will be slowed down by the presence of distracting advertisements.

Secondly, the researches have been focused on the effects that road elements have on the driver performance. The most of results seem to indicate that drivers simply tend to move away from obstacles along the roadside, and that this effect can extend to a considerable (lateral) distance. The above effects are a function of the type of obstacle, in particular, of perceived threat of the obstacle. This is particularly the case in narrower lanes. Other studies have been focused on the influence of the road environment characteristics on driver behaviour. De Ridder and Brouwer (2002) collected an effects series in behavioural driver in function of driver-infrastructure interaction (Table 1).

	Speed	Lateral position
Reduction in width of hard shoulder		To the left
Noise suppression screen		To the left
Reduction in lane width	Down	
Reduction in distance to roadside obstacles	Down	
Nature of roadside obstacles: - Trees vs. guardrail - Threatening object	Down in case of trees Down	
Undergrowth of continuous nature	Up	
Undergrowth of discontinuous nature	Down	

Buildings alongside road	Down
Vehicles next to road	Down
Reduction in road comfort	Down
Optical narrowing of lanes	Down
Reduction in sight distance	Down

Table 1 Summarized effects found in behavioural studies of driver-infrastructure interaction (Obtained from Janssen, De Ridder and Brouwer, 2004)

Taragin (1955) investigated the effect of obstacles on speed by putting three different sorts of objects on the highway shoulders. The findings aimed at the reduction in speed was somewhat stronger with two-lane highways than with four-lane highways. Furthermore, roadside obstacles result in a decrease on narrow roads only (less 6 m.) Tenkink (1989) showed that only with the narrowest lane width there was an effect of speed on the type of obstacle. Furthermore, this study suggested a relation between the type of obstacles and speed; speed was lower with obstacles with more serious consequences of an accident.

Following this line, De Vos, Hoekstra and Pieterse (1998) showed a decrease in driving speed with decreasing lane width. When a barrier was added at subject's right-hand side, driving speed decreased further compared to the no-barrier condition. The barrier also caused a shift of the mean lateral position, away from it.

Finally, it can be found in the literature studies focused on the influence the road characteristics on driver state. The parameter most studied with regard to road environment has been fatigue. Driver's fatigue has often been cited as a cause of road accidents (Knipling and Wang, 1994; Maycock, 1997; Thoren and Gaundel, 2003 and Williamson et al., 2001). Hancock and Desmond (2001) distinguish between fatigue caused by demands of driving task and fatigued linked to driver's state and predominantly to lack sleep. Thus, the fatigue can be caused by two sources the driver initial state before starting the driving and the characteristics of the drive and the road environment. This difference is very important because different causes of fatigue may require different ways of intervention. Therefore, have been described two broad categories as factors may influence the driver psychophysiological state: endogenous and exogenous factors (Cabon et al., 1996; Thiffault and Bergerson, 1997). The main endogenous factors are the time of day (i.e. the circadian rhythm), time since last sleep, sleep duration and sleep quality (Borbély, 1982; Lan et al., 2002 and Moore-Ede et al., 2004). These endogenous precursors are detrimental to driving performance because are directly associated with tonic variations physiological activation.

With regard to exogenous factors, the characteristics of road geometry and roadside environment can have an impact on driver performance by affecting arousal, alertness and information processing. A monotonous road environment can produce a decrease alertness and vigilance. This performance deterioration which is induced by under load may be as important as what is observed during over-demanding crowded urban situation where the driving performance might be affected too. Other authors have pointed out a third component, namely a time-on-task (Akersdet et al., 2004, Spencer and Gundel, 1998).

Roads which involve sustained, monotonous driving with little visual stimulus for the driver and where drivers aren't required to attend to either vehicle's controls or respond to multiple road users and junctions, are more likely to have sleep related accidents. Urban roads are less prone to fatigue crashes because the level of activity is so much greater, and helps to keep drivers active and alert (Reismann, 1996). Maycok (1995) found higher rates on motorways (20%) and non-built-up roads (14%) than on built-up roads (5%). And finally, Desmond and Matthews (1996) observed that driving performance decreases faster on straight road sections than on curves. Furthermore, other aspects of road have been related to driver fatigue. Such as, surface sort of the road. Foster et al (2001) have found a close link between vibrations received by the driver and fatigue.

2.3. Cost – Benefit Analysis

Cost-benefit analysis (CBA) is a technique that provides information to help decision makers to take the best choice, subject to constraints as resources availability. This procedure, based on the economic welfare theory and the principle of social efficiency, is designed to assess policies, projects, implementation of measures or an intervention in markets.

CBA evaluate projects (implementation of road infrastructure improvements); if the monetary value of the benefits, estimated according to the willingness-to-pay principle exceed the monetary value of the costs, estimated according to the opportunity cost principle, are efficient, whereas projects for which the benefits are smaller than the costs are inefficient. Basically, this procedure judges if the advantages (benefits) are greater than the disadvantages (costs).

In general, CBA is applied to solve social problems by finding the most efficient solutions. Typically these problems characteristics are:

- Involving public expenditures (investments).
- Multiple objectives problems, sometimes partly conflicting and requiring tradeoffs. Wide extent solutions.
- Objectives concern the provision of a non-marketed public good like safer roads.
- An efficient use of public funds.

Concerning the safety road framework, CBA is especially useful to help policy makers find the most efficient policy, measure or to evaluate measures already implemented.

As road safety is a very complex problem, decisions have to be made taking into account several issues as: the nature of the particular road safety problem, potential measures to implement, the resources available and different constraints. Each possible measure to solve the problem has to be assessed from different points of view: benefits such as casualty reductions, but also potential drawbacks such as increased pollution or greater travel time or the costs of implementation.

The advantages of using a CBA procedure to support a decision are:

- Transparency: this is likely to increase public acceptance since the various stages in the process are documented and can be defended against criticism.
- More comprehensive: all effects that may be predicted are brought together in a single framework.
- It is in accordance with the principles adopted by national Governments to ensure the best use of public money.
- The assessments can incorporate the best available knowledge about the effects of road safety measures.
- The assessments incorporate public preferences: they include, for example, the results of surveys which have investigated the public's willingness to pay for improved road safety.

On the other hand the disadvantages are:

- Not easy to extrapolate results.
- Ethical definitions and monetary considerations of human's life.
- Difficult estimations of all costs and benefits.
- Administration obstacles

The Cost-Benefit Analysis is technique aimed at finding whether a proposed objective is economically efficient and how efficient it is (and if alterations in the objective could make it more efficient). Various measures of efficiency are used to perform a CBA:

- the *net present* value of the project;
- the *cost-benefit ratio;*
- the *internal rate of return*.

Net present value

The net present value of a project is defined as the difference between the monetary value of all the benefits of a specific intervention and the value off all the costs required to realize them. Different benefits are usually added to obtain total benefits while negative benefits (e.g. increased travel time) are subtracted. The cost term usually describes the implementation costs of a measure, expressed in terms of the opportunity cost from a social point of view.

The net present value of a project is defined as:

Net present value = Present value of all benefits – Present value of all costs

The benefit term includes all effects that are valued monetarily in an analysis.

Cost-benefit ratio

It is defined as:

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

The cost term usually denotes the implementation costs of a measure, expressed in terms of the opportunity cost from a social point of view.

Obviously, there is a simple definitional relationship between net present value of benefit-cost ratio. When the net present value is positive, the benefit-cost ratio exceeds the value of 1.0.

Internal rate of return

It is defined as the interest rate that makes the net present value equal to zero. The internal rate of return is compared to some critical rate (e.g., a long-term market interest rate); if it is greater than this rate, then the project is worthy.

One of the greatest problems in cost-benefit analysis is to obtain valid and reliable monetary valuations of all relevant impacts. Sometimes it is interesting to perform a cost-effectiveness analysis in addition to, or in stead of, a CBA. A cost-effectiveness analysis is an analysis in which the objective is to find the cheapest way of realising a certain policy objective. In cost-effectiveness analyses, only one policy objective is considered.

Cost inputs are: Medical costs, cost of lost productive capacity, valuation of lost quality of life, cost of property damage and administrative costs. Some other studies also classified them as road safety, mobility, vehicle operating costs, environmental impacts and health impacts

The benefits come from casualty reduction and from preventing accidents.

To perform a CBA it is necessary a monetary valuation or estimation of all the costs and all the benefits a priori. This is most the difficult part of this procedure because the valuations vary substantially, so it is hard to obtain a reliable estimation. Values for an input are widely different depending on the approach used to estimate them, the country where they were calculated, index of corrections, data available, etc…

The most common methods for the estimation of the effects are:

- Expert opinions. Opinions of experts are the main element of choosing road safety measures.
- Before/after comparison. The accidents that occurred in a given period before the treatment have to be measured and those that occur in a given period after the treatment (if no other factors have influenced the safety conditions) are used to demonstrate the variation has to be attributed to the treatment.
- Cross-sections. The difference between cross-section type models and before/after type models is that, while the latter derive from observation of a statistical unit in different periods (before and after the treatment), the former derive from the observation of several statistical units in the same period.
- In-depth analysis. The principal objective is to evaluate the performance of the vehicle in terms of passive safety and accident causation (risk factors).
- Econometric macro models. The occurrence of the accident is linked to a series of factors. Nevertheless, the number of accidents is linked to the exposure to risk, which is

to say, to the level of mobility and choice of transport mode. These variables are, in turn, correlate with macroeconomic variables such as GNP, the price of consumer goods, stock of infrastructures, population.

- Interviews. Interviews (questionnaires) are used in some cases in which it is difficult to perform reliable direct measurement, by means of observation in the field or laboratory experiments, of the results of the measures.
- Experimental investigations. Quantification of the effects of innovative road safety measures.
- Crash tests. The effects of the passive safety measures can be quantified trough a statistical analysis of the consequences of the accidents in presence and in absence of the measures (comparison group), in-depth analysis of the accidents, comparison before/after, with reference to the moment of introducing of the measures and crash test, with dummies.
- Other methods:
  - Literature analysis. With this method, the results achieved in similar experiences are used to forecast effects of measures to be implemented.
  - Detailed analysis of accidents occurred in the selected location. This kind of analysis allows to subdivide accidents into different groups, according to different crash patterns and to select target accidents that could be reduced through the implementation of particular measures.

Moreover, reliable data is necessary to estimate all the factors and to extrapolate the results. Sometimes the data are circumscribed to a region or a country so the estimations and consequently the results are not useful for other countries.

As CBA analyses are based on welfare economics and require all policy impacts to be stated in monetary terms, some experts find the idea of assigning a monetary value to lifesaving or to quality of life, meaningless and ethically wrong.

There are some constraints related to the organisation of policy making as different criteria to choose the main objectives, bureaucracy or wrong timing of decision making process.

2.4. Main accident scenarios

A typical scenario can be defined as a prototype of accident process corresponding to a series of accidents which present overall similarities regarding the chain of facts and causal relationships throughout the various accident stages. On the other hand, RANKERS deemed adequated to separate the recommendations or countermeasures provided by this catalogue according to different accident scenarios. Therefore, for each road section, once the road safety problems are identified, it will be easier to choose the proper solutions. Moreover, a countermeasure may have different effectiveness depending on the accident scenario.

WP4 took advantage of the work developed by WP1[1] and included the scenarios developed there for double carriageway roads. In the case of single carriageway roads, WP4 developed statistical analyses over the Spanish Injury Accident Database in order to develop accident scenarios for this type of roads. Through cluster analyses, scenarios were obtained according to descriptive variables related to the type of accident, the road infrastructure and the vehicle.

The catalogue of recommendations is structured according to the accident scenarios that are described as follows.

2.4.1. Double carriageway scenarios

The scenarios developed by WP1 for double carriageway roads are the following ones:

Loss of control

1. Loss of control with only one car at the origin due to drowsiness, malaise or distraction.
2. Loss of control of a vehicle after travelling on water (aquaplaning) or on a particular slippery road surface (hail, ice, oil) or a hole.
3. Loss of control due to the high speed.
4. Tyre burst or blowout, loss of control of the vehicle, run off accident.
5. Loss of control of a single vehicle on an exit/entry slip road.
6. Object on the roadway.
7. Collision with car ahead due to drowsiness or wrong evaluation.

Rear – end collision

8. Rear – end collision with a vehicle stopped on the shoulder (emergency lane).
9. Rear – end collision with a vehicle stopped on the driving lanes.
10. Rear – end collision due to traffic slowdown.
11. Rear – end collision at motorway tolls.

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[1] More information about these scenarios can be found in deliverable D1.2 – Scenario Definition. www.rankers-project.com

Lane changing collision

12. Lane changing accident at the beginning or at the end of overtaking.
13. Loss of control during overtaking.

Other types of collision

14. Pedestrian crossing.
15. Pedestrian on driving emergency lane.
16. Collision with an animal.
17. Wrong way entrance on motorway.

These scenarios are based on the analysis of 315 in – depth accident investigations provided by RANKERS partners in WP1.

2.4.2. Single carriageway scenarios

Through the statistical analysis of the Spanish Injury Accident Database (2003 – 2005), WP4 obtained a set of accident scenarios in single carriageway roads. The cluster method forms groups of accidents according to their similarity according to a set of variables defined by the analyist. In this case, the variables chosen were the following ones:

- Type of collision.
- Type of vehicle.
- Severity of the accident.
- Weather conditions.
- Visibility restrictions.
- Age of the driver.
- Pavement condition.
- Accident severity.

The analysis was divided in two main groups: at intersection accident and non intersection accidents.

The scenarios obtained are as follows:

Junction accidents

18. Lateral collisions at junctions.
19. Night time collisions at roundabouts.
20. Fatal collisions at junctions.

21. Light accident with wet pavement conditions at junctions.

Out of junction accidents

22. Run – off accidents at curves with degradated weather conditions.
23. Light accidents at straight sections.
24. Fatal collisions at straight/curve sections related with fatigue and distraction.

3. Assessing the cost effectiveness of infrastructure safety measures

3.1. *Theoretical background*

The economic evaluation of low cost measures is based on the comparison between the cost of the measure to be installed and the benefits produced by its installation.

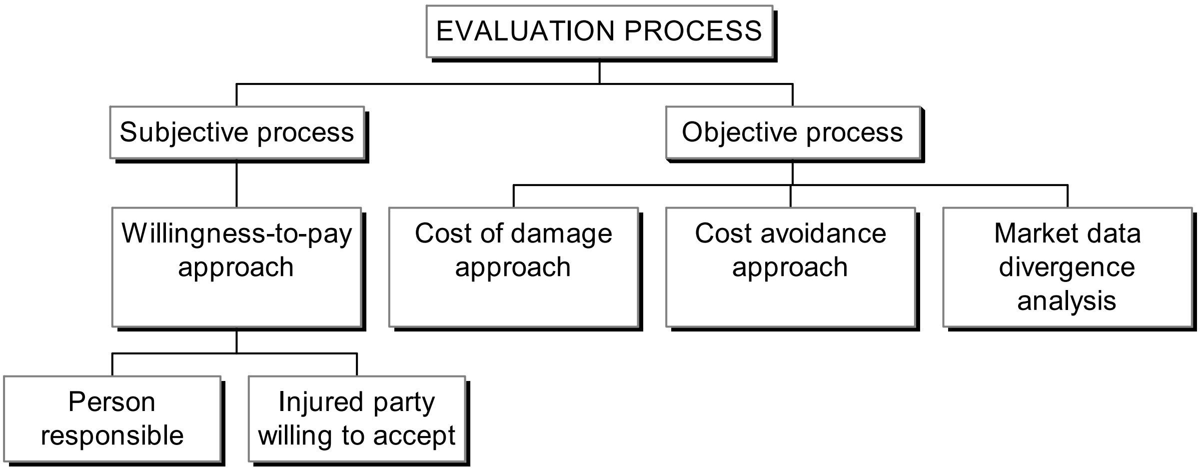

Figure 1 Theoretical approaches to Cost – Benedit Analyses

Although costs can usually be clearly defined in time as they are known factors to the operators undertaking for most of the countermeasures, there is no information available about the traffic flow, the accident rate or the severity of the accidents. In most cases, in fact, only the accident reduction rate is given from statistics. When the accidents reduced have a similar severity within a given scenario, it is possible to calculate the effectiveness of a certain countermeasure, if the cost for installation, operation and maintenance is known and the life time of the countermeasure is predictable.

The reduction in the total number of fatalities can be used as an indicator for the benefit of a countermeasure, as for instance 20% or 0.20. The related costs can be expressed as the installation costs plus the operation and maintenance costs discounted according to the interest rate for this class of countermeasures and an assumed life time, often 15 years for a directed safety measure.

The numerical value for the ranking purpose can be expressed as:

$$RF = ARR * pwf\ (n, i) / [I + O * pwf\ (n, i)]$$

RF is the ranking factor, a value which should be the highest possible. *ARR* is the accident reduction rate expressed as a percentage or a part of the former accidents. The letter *I* represents the installation cost for the specific countermeasure, often a single payment, and *O* is the yearly operation or maintenance cost for the same countermeasure.

With the letter *n* we indicate the total lifetime of the countermeasure and with *i* the interest rate. The factor indicated as *pwf* is the discount factor or present worth factor for a uniform series of payments and is itself calculated with the formula:

$$pwf\ (n, i) = [(1+i)^n -1) / (i *(1+i)^n]$$

As an example if the take values for 4, 15 and 20 years and we consider an interest rate of 4 % then the above formula yields discount factors of 3.63, 11.12 and 13.59 respectively.

If we apply the ranking formula to the countermeasure “*roadside obstacle*” in the scenario “*Loss of control with only one car at the origin due to drowsiness, malaise or distraction*” then we will have a ranking factor of $4.2 * 10^{-5}$. We obtain this value through the formula:

$$RF = (0.11 *13,59) / (30,000 + 425 * 13.59) = 4.2 * 10^{-5}$$

where:
ARR = 0.11
pwf =13,59 for n = 20 years and i = 4 %

I = 30,000 Euro/km
O = 425 Euro/km per year

Using the same scenario but with the countermeasure “*Smooth aggressive side slopes*” will, on the other hand, yield the following results:

$$RF = (0.10 * 13.59) / 55,000 = 2.5 * 10^{-5}$$

As we can clearly see this produces a smaller ranking factor than for the first countermeasure. We can therefore safely assert that the first countermeasure “*Remove roadside obstacles*” gives more value for money or is more cost effective.

However it cannot be ascertained if the benefit is greater than the cost, because we do not possess data on the traffic flow and the accident rate or the number of accidents and their severity, values which can give the cost for a single accident.

In order to apply this methodology, some assumptions have been made. For some countermeasures, the available info related to costs did not provide figures but ranges like low, medium or high. For each of these categories, a maximum threshold has been adopted: low costs for those less than 6,000€/km; medium costs for those between 6,000€/km and 50,000 €/km and high costs for those higher than 50.000€/km. For accident reduction percentages, whenever the reduction did not neither provided figures, the following was adopted: low effectiveness for those lower than 0.10 accident reduction factor; medium for those between 0.10 and 0.35 and high for those higher than 0.35.

This methodology by itself already constitutes an innovation of the RANKERS project in the field of Cost – Benefit analyses. It has been applied when possible to the list of countermeasures that the catalogue includes. Nevertheless, in some cases the information available regarding the different costs and most of all regarding the effectiveness is not enough to apply this methodology.

4. Catalogue of remedial measures

The catalogue of recommendations is a compendium of road infrastructure safety countermeasures, grouped by the accident scenarios they are relevant to, that are ranked according to the relationship between their effectiveness and costs, whenever this is possible.

The objective of the catalogue is to provide road operators with a practical tool that is able to advise which countermeasures are relevant to specific problems. Moreover, it is intended to give insight on the different effectiveness and costs of the available solutions. It can help to idendify 'low cost' but 'high effective' countermeasures.

Nevertheless, this catalogue has to be considered as a reference guide but not as a standard. Effectiveness and costs of countermasures may have important variations according to the different countries or even regions where they are implemented. Therefore, the consortium recommends using it as a complement to all the necessary information to take the decisions (safety inspections of the road sections, accident data, traffic flow, previous experience in the specific locations with road infrastructure countermeasures).

4.1. Using the catalogue

The catalogue is structured according to:

- Type of carriageway (single or double).
- Scenario.

For each scenario the list of recommendations gathers the following information:

- Expected impact: AA (Accident avoidance) or RD (Reduction of Damage).
- Effectiveness: estimation of the percentage of reduction of accidents. For those countermeasures dealing with the reduction of the severity of the accident it refers to the percentage of reduction of fatal or serious accidents.
- Costs: installation (including the purchase cost), operational and expected lifetime.
- Affected users: all vehicles, light vehicles, heavy vehicles or PTW.

Together with the list of the recommendations, for each scenario a list of literature references upon which the estimations of effectiveness are based is provided. The references are numbered so it can be identified to which recommendation they are related to.

Before selecting the recommendations it is advisable to carry out some previous steps over the road section under analysis:

1. Identify the geometric layout of (type of carriageway, alignment, …)
2. Carry out a safety inspection in order to review the status of all road infrastructure elements.
3. Analyse the previous accident data, identifying the most frequent type of collision as well as the most frequent weather, time, vehicle characteristics. This should help to identify the type of scenario that most fits to the safety problems of the road section.
4. The road operator or safety expert should review the countermeasures implemented in the previous 3 – 5 years in order to analyse their performance.
5. It would also be advisable to get data about the surrounding road sections. Sometimes, after the implementation of a countermeasure the road safety problem is just moved 1 km. further away or other adjacent road sections.

Then, it will become easier to the potential users of the catalogue to directly select the recommendations within the appropriate scenarios and also to discard those countermeasures that may have not performed positively in previous experiences for a particular road section.

From the perspective of the RANKERS approach, the previous application of the Road Safety Index[2] would help to identify the particular issues of the road infrastructure that may present deficiencies or problems to be solved.

As it can be observed in the catalogue, the estimations when available for the costs and benefits are given separately. This allows potential users to calculate their own estimations when costs differ largely from the estimations provided in this catalogue.

[2] RANKERS Deliverable D4.2 "The Road Safety Index"

4.2. Listing of remedial measures

1. Loss of control with only one car at the origin due to drowsiness, malaise or distraction

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Implement audible edge markings (rumble strips or other) on the right and left-hand side of the carriageway [1][2]	AA	3 – 21 % If audible edgelines missing Δ40% accidents	2000 €/km	0 €/km	-	0.000105 – 0.000015	All vehicles
Construct or widen the emergency lane [3]	AA	33 %	190000-380000 €/km	0 €/km	-	$8.64*10^{-7}$ – $1.73*10^{-6}$	All vehicles
Centerline rumble strip	AA	two-lane roads 25% reduction in crashes frontal and opposing-direction sideswipe crashes	-	0 €/km		Prevent vehicles to go into opposite travelling vehicles -	Cars and trucks. Influence on motorcycle and bicycle riders not proved.
Construct rest areas	AA	-	134000-185000 €	-	-	-	All vehicles

			/area				
Construct or widen a left hard strip	AA	-	-	-	-	-	All vehicles
Make roadside obstacles traversable	RD	High	Low	0 €	20	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside equipment	RD	Medium to High	High	0 €	20	$9.5*10^{-5}$	All vehicles
Install safety barriers when necessary [2][4]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Remove roadside obstacles [3][4]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [3]	RD	16 %	50000 €/km	0 €	20	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20	$2.9*10^{-5}$	All vehicles

Further reading	Author, year	Publisher
1. NCHRP report 500, volume 6: A Guide For Addressing Run-Off-Road Collisions	NCHRP, 2003.	NCHRP
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
3. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
4. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
5. Safety reviews of existing roads	Alfonso Montella	
6. US Experience with Centerline Rumble Strips on Two Lane Roads: Pattern Research and North America Usage	Eugene R. Russell, Margaret J. Rys, Troy S. Brin	Department of Civil Engineering Kansas State University
7. Safety Evaluation of Centerline Rumble Strips: A crash and driver behaviour analysis	David A. Noyce, Vetri Venthan Elango	School of Civil and Environmental Engineering Georgia Institute of Technology Atlanta

2. Loss of control of a vehicle after travelling on water (aquaplaning) or on a particular slippery road surface (hail, ice, oil) or a hole

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Implement snow clearance and road surface treatments [2][4]	AA	Snow clearance: 35 %[1] Salting: 24 %[1]	2000 - 6000€	Snow clearance: 31-38 €/km and snowy day. Salting: 11-16 €/km and icy day. Fixed cost for winter organisation: 2000-6000 €/km	Sanding- Short lifetime, since the sand is blown away by passing cars.	0.001 – 0.0005	All vehicles
Measure the friction and change and renew regularly the road surface coating [1]	AA	4 – 10 %	80000-160000 €/km	0 €	5	$3.3 \cdot 10^{-6} – 1.6 \cdot 10^{-5}$	All vehicles
Make roadside obstacles traversable	RD	High	Low	0 €	20	$2.2 \cdot 10^{-4} – 7.9 \cdot 10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20	$7.9 \cdot 10^{-4}$	All vehicles

Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside equipment	RD	Medium to High	High	0 €	20	$9.5*10^{-5}$	All vehicles
Install safety barriers when necessary [2][4]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Implement median barriers	RD	20%	High	0€	20 years	$5.4*10^{-5}$	All vehicles
Remove roadside obstacles [3][4]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [3]	RD	16 %	50000 €/km	0 €	20	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20	$2.9*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
2. Beräkningsmodell för vinterväghållningskostnader	Anita Ihs, Staffan Möller, 2004.	Swedish National Road and Transport Research Institute
3. Guidelines For Roadside Infrastructure	RISER, 2005.	RISER

On New And Existing Roads		
4. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
5. Effects of Weather-Controlled variable message signing on driver behaviour	Pirkko Rämä	Nordic Road & Transport Research
6. The handbook of safety measures	Rune Elvik& Truls Vaa	Institute of Trasnsport Economics, Oslo, Norway

[1]First 24 hours after measure

3. Loss of control due to high speed

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Install rumble strips on the road on straight alignments before curve [2][3]	AA	9-15 %	6000 €/km	0 €	20 years	$2.03*10^{-4}$ – $3.3*10^{-4}$	All vehicles
Install speed cameras [1]	AA	19 %	2000-6000 €/km	400-4000 €/km	20 years	$4.5*10^{-5}$ – $3.4*10^{-4}$	All vehicles
Increase the curve radius [1][4]	AA	12-50 %	1500000-3000000 €/km	0 €	20 years	$5.4*10^{-6}$- $4.5*10^{-5}$	All vehicles
Implement variable speed limit signs	AA	5-17%	-	0 €	20 years	-	All vehicles
Make roadside obstacles traversable	RD	High	Low	0€	20 years	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20 years	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20 years	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside	RD	Medium to High 46-69%	High	0 €	20 years	$9.5*10^{-5}$	All vehicles

equipment. Crash cushions		reduction in injury and fatal accidents					
Install safety barriers when necessary [4][1]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Remove roadside obstacles [2][1]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20 years	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [2]	RD	16 %	50000 €/km	0 €	20 years	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20 years	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20 years	$2.9*10^{-5}$	All vehicles

Further reading	Author, year	Publisher
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
2. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
3. NCHRP report 500, volume 6: A Guide For Addressing Run-Off-Road Collisions	NCHRP, 2003.	NCHRP
4. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
5. Evaluation of variable speed limits to	Chris Lee, Bruce Hellinga, Frank	Department of Civil

improve traffic safety	Saccomanno	Engineering, University of Waterloo, Ont, Canada
6. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.

4. Tyre burst or blowout, loss of control of the vehicle, run off

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Install rumble strips on the road on straight alignments before curve [2][3]	AA	9-15 %	6000 €/km	0 €	20 years	$2.03*10^{-4}$ – $3.3*10^{-4}$	All vehicles
Install speed cameras [1]	AA	19 %	2000-6000 €/km	400-4000 €/km	20 years	$4.5*10^{-5}$ – $3.4*10^{-4}$	All vehicles
Increase the curve radius [1][4]	AA	12-50 %	1500000-3000000 €/km	0 €	20 years	$5.4*10^{-6}$- $4.5*10^{-5}$	All vehicles
Implement variable speed limit signs	AA	5-17%	-	0 €	20 years	-	All vehicles
Make roadside obstacles traversable	RD	High	Low	0€	20 years	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20 years	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20 years	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside	RD	Medium to High 46-69%	High	0 €	20 years	$9.5*10^{-5}$	All vehicles

equipment. Crash cushions		reduction in injury and fatal accidents					
Install safety barriers when necessary [4][1]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Remove roadside obstacles [2][1]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20 years	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [2]	RD	16 %	50000 €/km	0 €	20 years	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20 years	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20 years	$2.9*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
2. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
3. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.

5. Loss of control of a single vehicle on an exit/entry slip road

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Install rumble strips on the roadway [1][3]	AA	9-15 %	6000 €/km	-	20 years	0.0002 – 0.0003	All vehicles
Implement variable speed limit signs	AA	5-17%	-	-	-	-	All vehicles
Make roadside obstacles traversable	RD	High	Low	0€	20 years	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20 years	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20 years	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside equipment. Crash cushions	RD	Medium to High 46-69% reduction in injury and fatal accidents	High	0 €	20 years	$9.5*10^{-5}$	All vehicles
Install safety barriers when necessary [4][1]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Remove roadside	RD	11 %	20000-	250-625	20 years	$3.1*10^{-5}$ –	All

obstacles [2][1]			40000 €/km	€/km (1994)		$6.38*10^{-5}$	vehicles
Relocate roadside obstacles out of safety zone [2]	RD	16 %	50000 €/km	0 €	20 years	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20 years	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20 years	$2.9*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
1. NCHRP report 500, volume 6: A Guide For Addressing Run-Off-Road Collisions	NCHRP, 2003.	NCHRP
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
3. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
4. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
5. Evaluation of variable speed limits to improve traffic safety	Chris Lee, Bruce Hellinga, Frank Saccomanno	Department of Civil Engineering, University of Waterloo, Ont, Canada

6. Object on the roadway

No infrastructure countermeasures have been found consistent for this scenario. However, in France or Spain for instance, some special messages are broadcast on a dedicated motorway radio channel, as well as specific messafes are desplayed on VMS.

7. Collision with car ahead due to drowsiness or wrong evaluation

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Install speed cameras [1]	AA	19 %	2000-6000 €/km	400-4000 €/km	3-5 years	$4.58 \cdot 10^{-5}$ – 0.0003	All vehicles
Construct rest areas	AA	-	134000-185000 € /area	0 €	20 years	$6.43 \cdot 10^{-5}$ – $7.99 \cdot 10^{-5}$	All vehicles
Display warnings of fog or snow on variable message signs [2][3]	AA	84 % reduction of accident in fog	85000 €/km	4250-6800 €/km	3-5 years	-	All vehicles

Further reading	Author, year	Publisher
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
2. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
3. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration

8. Rear-end collision with a vehicle stopped on the shoulder (emergency lane)

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Implement audible edge markings (rumble strips or other) on the right and left-hand side of the carriageway [2][3]	AA	3 – 21 %	2000 €/km	0 €	20 years	0.0002 – 0.0014	All vehicles
Construct emergency lanes [1][2]	AA	0.6 m: 19 % 1.2 m: 35 % 1.8 m: 48 % 3.0 m: 66 %	0.6 m: 75000-150000 €/km 1.2 m: 150000-300000 €/km 1.8 m: 230000-460000 €/km 3 m: 400000-800000 €/km	0 €	20 years	$1.1*10^{-5}$ – $3.4*10^{-5}$	
Widen the existing emergency lanes if not wide enough [1][2]	AA	0 m to 0.6 m: 19 % 0.6m to 1.2 m:	0.6 m widening of hard	0 €	20 years	$8.5*10^{-6}$ – $3.4*10^{-5}$	

		16 % 1.2m to 1.8 m: 13 % 1.8m to 2.4 m: 10 % 2.4m to 3.0 m: 9 %	shoulder: 75000-150000 €/km				

Further reading	Author, year	Publisher
1. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
3. NCHRP report 500, volume 6: A Guide For Addressing Run-Off-Road Collisions	NCHRP, 2003.	NCHRP

9. Rear-end collision with a vehicle stopped on the driving lanes

Within this scenario the following infrastructure countermeasures have been found although no information related to costs and effectiveness have been found:

- Warn drivers through VMS coupled to automativ systems detecting incidents.
- Use flashing lights on emergency call boxes to warn drivers about the accident.

10. Rear-end collision due to traffic slowdown

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking facor**	**Affected users**
			Installation	Operational	Expected lifetime		
Paint chevrons for speed reduction	AA	1% ; 15% speed reduction Reduce "relevant" crashes by 35 % to 70% Total crashes reduced 5%	Low cost	0 €	5 years	0.0007 – 0.001	All vehicles
Widen the existing emergency lanes if not wide enough [3][2]	AA	0 m to 0.6 m: 19 % 0.6m to 1.2 m: 16 % 1.2m to 1.8 m: 13 % 1.8m to 2.4 m: 10 % 2.4m to 3.0 m: 9 %	0.6 m widening of hard shoulder: 75000-150000 €/km	0 €	20 years	$8.5*10^{-6}$– $3.4*10^{-5}$	All vehicles
Construct emergency lanes [3][2]	AA	0.6 m: 19 % 1.2 m: 35 % 1.8 m: 48 %	0.6 m: 75000-150000	0 €	20 years	$1.1*10^{-5}$– $3.4*10^{-5}$	All vehicles

		3.0 m: 66 %	€/km 1.2 m: 150000-300000 €/km 1.8 m: 230000-460000 €/km 3 m: 400000-800000 €/km				
Automatic warning of queues with variable message signs [1][2]	AA	16 %	85000 €/km	4250-6800 €/km	3-5 years	$1.2*10^{-5}$– $1.5*10^{-5}$	All vehicles
Install traffic regulation devices and encourage drivers to adapt their speeds through variable message signs	AA	15 %	85000 €/km	4250-6800 €/km	3-5 years	$1.1*10^{-5}$– $1.4*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
1. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
3. Guidelines For Roadside Infrastructure	RISER, 2005.	RISER

On New And Existing Roads		
4. Report on Passive Speed Control Devices. Task 20. Speed and Traffic Operations Evaluation	Heather Rothenberg,	MassSAFE Massachusetts Traffic Safety Research Program University of Massachusetts
5. Evaluation of the converging chevron pavement marking pattern at one Wisconsin location	Alex Drakopoulos - Georgia Vergou	AAA Foundation for Traffic Safety

11. Rear-end collision at motorway tolls

Within this scenario, the consortium has found relevant to implement audible edge markings across the carriageway lanes before the the toll stations. Nevertheless, no specific information has been found for this scenario regarding costs and effectiveness. Orientative info can be found in the precious scenarios where this countermeasure was found to be relevant.

12. Lane changing accident at the beginning or at the end of overtaking

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Install speed cameras [2]	AA	19 %	2000-6000 €/km	400-4000 €/km	20 years	$4.5*10^{-5}$ – 0.0003	All vehicles
Install traffic regulation devices and encourage drivers to adapt their speeds through variable message signs	AA	15 %	85000 €/km	4250-6800 €/km	3-5 years	$1.1*10^{-5}$ – $1.4*10^{-5}$	All vehicles
Make roadside obstacles traversable	RD	High	Low	0€	20 years	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20 years	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20 years	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside equipment. Crash cushions	RD	Medium to High 46-69% reduction in injury and fatal accidents	High	0 €	20 years	$9.5*10^{-5}$	All vehicles
Install safety barriers	RD	47 %	60000-	1000-5000	20 years	$3.8*10^{-5}$	All

when necessary [4][1]			100000 €/km	€/km		– $8.6*10^{-5}$	vehicles
Remove roadside obstacles [2][1]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20 years	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [2]	RD	16 %	50000 €/km	0 €	20 years	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20 years	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20 years	$2.9*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
1. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
3. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.

13. Loss of control during overtaking

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Install speed cameras [2]	AA	19 %	2000-6000 €/km	400-4000 €/km	20 years	$4.5*10^{-5}$ – 0.0003	All vehicles
Install traffic regulation devices and encourage drivers to adapt their speeds through variable message signs	AA	15 %	85000 €/km	4250-6800 €/km	3-5 years	$1.1*10^{-5}$ – $1.4*10^{-5}$	All vehicles
Make roadside obstacles traversable	RD	High	Low	0€	20 years	$2.2*10^{-4}$ – $7.9*10^{-4}$	All vehicles
Treat barrier terminations (no blunt ends, no springboards)	RD	Medium to High	Low	0 €	20 years	$7.9*10^{-4}$	All vehicles
Protect motorcyclists against crashes against with motorcycle-friendly road restraint systems	RD	High	Low to Medium	0 €	20 years	$1.9*10^{-4}$	PTWs
Implement energy absorbing roadside equipment. Crash cushions	RD	Medium to High 46-69% reduction in injury and fatal accidents	High	0 €	20 years	$9.5*10^{-5}$	All vehicles

Install safety barriers when necessary [4][1]	RD	47 %	60000-100000 €/km	1000-5000 €/km	20 years	$3.8*10^{-5}$ – $8.6*10^{-5}$	All vehicles
Remove roadside obstacles [2][1]	RD	11 %	20000-40000 €/km	250-625 €/km (1994)	20 years	$3.1*10^{-5}$ – $6.38*10^{-5}$	All vehicles
Relocate roadside obstacles out of safety zone [2]	RD	16 %	50000 €/km	0 €	20 years	$4.3*10^{-5}$	All vehicles
Smooth aggressive sideslopes	RD	5 – 15 %	55000 €/km	0 €	20 years	$1.2*10^{-5}$ – $3.7*10^{-5}$	All vehicles
Treat natural obstacles (safer redesign of ditches for instance)	RD	12 %	55000 €/km	0 €	20 years	$2.9*10^{-5}$	All vehicles

Further reading	**Author, year**	**Publisher**
4. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
5. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
6. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.

14. Pedestrian crossing

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Create an underpass or a overpass [1]	AA	69 – 90 % of pedestrian accidents	50000 €/bridge	0 €	20 years	0.0001 – 0.0002	Pedestrians
Layout of fences [1]	AA	25 % of all accidents involve pedestrians	25000-30000 €/km	0 €	20 years	0.0001	Pedestrians
Review fences and repair the holes [1]	AA	25 % of all accidents involves pedestrians	25000-30000 €/km	0 €	5 years	0.0001	Pedestrians

Further reading	Author, year	Publisher
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration

15. Pedestrian on driving or emergency lane

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Widen the existing emergency lanes if not wide enough [1][2]	AA	0 m to 0.6 m: 19 % 0.6m to 1.2 m: 16 % 1.2m to 1.8 m: 13 % 1.8m to 2.4 m: 10 % 2.4m to 3.0 m: 9 %	0.6 m widening of hard shoulder: 75000-150000 €/km	0 €	20 years	$8.5*10^{-6}$– $3.4*10^{-5}$	All users
Construct emergency lanes [1][2]	AA	0.6 m: 19 % 1.2 m: 35 % 1.8 m: 48 % 3.0 m: 66 %	0.6 m: 75000-150000 €/km 1.2 m: 150000-300000 €/km 1.8 m: 230000-460000 €/km 3 m:	0 €	20 years	$1.1*10^{-5}$– $3.4*10^{-5}$	All users

			400000-800000 €/km				

Further reading	Author, year	Publisher
1. Guidelines For Roadside Infrastructure On New And Existing Roads	RISER, 2005.	RISER
2. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration

16. Collision with an animal

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Use scent signals to frighten game [2]	AA	70 %	0 €	300-1200 €/km	20 years	0.002-0.005	All vehicles
Create a sight clearance of woodland [2]	AA	20 %	4000-8000 €/km	250-360 €/km	20 years	0.002-0.003	All vehicles
Erect wild life fences along the roads [1][2]	AA	40-80 %	20000-30000 €/km	0 €	20 years	0.0001-0.0005	All vehicles
Build overpasses for animals	AA	70 – 100 %	1700000 €/bridge	0 €	20 years	$5.5*10^{-6}$	All vehicles
Implement warning signs of high probability of wild animals crossing the roadways [2]	AA	0 - 2% (Limited effect, actually. Drivers do not even pay attention to the signs)	210 €/sign	0 €	20 years	≈ 0	All vehicles

Further reading	Author, year	Publisher
1. Effektsamband 2000: Nybyggnad och förbättringar: Effektkatalog	Swedish National Road Administration, 2001.	Swedish National Road Administration
2. The Handbook of road safety measures	Rune Elvik, Truls Vaa, 2004.	Insitute of Transport Economics, Trondheim, Norway.

17. Wrong way entrance on motorway

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Segregation of the lanes on the bidirectional roads, install a road sign showing a brightly coloured raised hand and paint directional arrows on the ground	AA	80 %	Traffic signals: 3.500 €/junction Temporary delineators: 21.000 €/junction Physical separation: 50.000 €/junction	0 €	20 years	0.0002 – 0.003	All users

18. Lateral collisions at junctions.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The road side area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [3]	Göran Nilsson, 2002.	Swedish National Road

[3] AA: Accident avoidance; RD: reduction of damage

		Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

19. Night collisions at roundabouts

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The road side area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [4]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[4] AA: Accident avoidance; RD: reduction of damage

20. Fatal collisions at junctions.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The road side area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [5]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[5] AA: Accident avoidance; RD: reduction of damage

21. Light accidents with wet pavements conditions at junctions.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	Author, year	Publisher
10. The road side area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [6]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[6] AA: Accident avoidance; RD: reduction of damage

22. Run-off accidents at curves with degraded weather conditions.

Associated countermeasures	Expected impact	Effectiveness	Costs			Ranking factor	Affected users
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder and on the middle of the road	AA	30 - 50 %.	By milling 2 - 3 €/m	0 €	3 - 10 years	0.002 – 0.003	All vehicles
Remove/modify roadside obstacles	RD	90 %	Modifying of wooden pole less than 100 €.	0 €	20 years	0.012	All vehicles
Increase recovery zone	RD	50 %.	High	Slight costs because of cutting small trees every two years	20 years	0.0001	All vehicles
Protect roadside obstacles	RD	100 %.	20 €/m	0 €	20 years	0.0006	All vehicles

Further reading	Author, year	Publisher
10. The road side area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [7]	Göran Nilsson, 2002.	Swedish National Road

[7] AA: Accident avoidance; RD: reduction of damage

		Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

23. Light accidents at straight sections.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The roadside area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [8]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[8] AA: Accident avoidance; RD: reduction of damage

24. Fatal collisions at straight/curve sections related with fatigue and distraction.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The roadside area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [9]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[9] AA: Accident avoidance; RD: reduction of damage

25. Run off accidents due to excessive speed at curve sections.

The following are the countermeasures related to infrastructure recommended for this scenario. Nevertheless, no reliable information has been found about the different cost and effectiveness.

Associated countermeasures	**Expected impact**	**Effectiveness**	**Costs**			**Ranking factor**	**Affected users**
			Installation	Operational	Expected lifetime		
Add rumble strips near hard shoulder	AA						Light vehicles
Increase recovery zone	RD						All vehicles
Soften roadside slope	AA						All vehicles
Remove/modify roadside obstacles	RR						All vehicles
Protect roadside obstacles	RR						All vehicles
Implement measures against driver drowsiness	AA						Light vehicles

Further reading	**Author, year**	**Publisher**
10. The roadside area and safety fences.	Li Ljungblad, 2000.	Institute for Road Safety Research (SWOV).
11. Motorcyclists and guardrails. [10]	Göran Nilsson, 2002.	Swedish National Road Administration
12. Drowsiness in traffic.	Anna Anund, Jörgen Larsson, 2002.	Swedish National Road and Transport Research Institute

[10] AA: Accident avoidance; RD: reduction of damage

5. Conclusion

This deliverable represents the main results of Tasks 4.1 and 4.2 within the RANKERS project. Tasl 4.1 (Cost – Benefit Analysis) was aimed at developing a methodology suitable to assess the relationship between costs and effectiveness when road infrasfructure countermeasures are implemented in real road sections. On the other hand, Task 4.2 (Ranking of Recommendations) has the objective of developing a catalogue of remedial infrastructure countermeasures in order to improve road safety. Moreover, this catalogue could be applied once the Road Safety Index (Deliverable 4.2) has assessed the actual safety level of the road section.

The main innovations of this deliverable can be summarized as follows:

- A new method has been developed in order to compare the relation between costs and effectiveness between a set of countermeasures. Although costs can usually be clearly defined in time as they are known factors to the operators undertaking for most of the countermeasures, there is no information available about the traffic flow, the accident rate or the aciednt severity. In most cases, in fact, only the accident reduction rate is given from statistics. When the accidents reduced have a similar severity within a given scenario, it is possible to calculate the effectiveness of a certain countermeasure, if the cost for installation, operation and maintenance is known and the life time of the countermeasure is predictable. The methodology developed in Task 4.1 and presented in Section 3 of this report has allowed estimating cost – effectiveness ranges among various road infrastructure countermeasures and therefer has made the ranking between them possible.
- The consortium deemed adequate to group the countermeasures in accident scenarios. This would allow choosing the best remedial action for each road section as in some cases the same countermeasure might not have the same effectiveness in different scenarios. Therefore, once the Road Safety Index has identified specific infrastructure problems that are related to certain type of collisions the catalogue can provide the adequeate solutions. This approach has some difficulties that are also explained in this section and are mainly related with the fact that many studies about countermeasures effectiveness do not split it by different scenarios.
- The catalogue developed is a useful complement of the Road Safety Index. An integrated safety approach could be used when planning the application of infrastructure countermeasures on real road sections. The RSI would be able to detect the aspects of the infrastructure that could be improved and the ranking would provide the most suitable option in terms of cots (installation and maintenance) and the effectiveness (reduction of accident and severe injuries).

Nevertheless, the consortium has encountered some difficulties that are relevant to mention and that may constitute future research needs:

- Most of the previous research studies analyzed in the project related to countermeasures effectiveness do not distinghuish as much as the consortium deems appropriate in accident scenarios. This kind of research would allow investigating the countermeasures effectiveness for different scenarios.
- More precise and reliable information regarding the cost of countermeasures, most of all maintenance costs, would improve the estimations of cost – benefit analyses.
- The consortium has found much more information for double carriageway roads countermeasures than for single carriageway roads. Therefore, it would be advisable to explore deeper the best countermeasures and its effectiveness for single carriageway roads. Moreover, this type of roads concentrates the highest figures about fatalities and severe injuried people.

The consortium recommends to apply this catalogue after visiting the real road sections and also looking at the previous accident data in the road section under analysis. Road safety inspections can provide useful information that might be specific of the road under study and might influence in the final selection of the countermeasure. National or regional standards can also constraint the selection of the countermeasures, so this should also be taken into consideration.

The information gathered in this catalogued is just updated until the date of publication of this report. Future research projects and experiments may bring new data or even new countermeasures in the coming years.

Finally, the catalogue presented in this report is deemed to contribute to the enhancement of raod safety levels through economic actuations on road infrastructure. It complies with the planned objectives and has provided also key facts where more research is necessary in the coming years.