Network

Safety

Management

NSM

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1 Introduction

1.1 Contents

Network Safety Management comprises a methodology to analyse existing road networks from the traffic safety point of view. This paper mainly contains the first step of a comprehensive safety analysis which enables road administrations to detect those sections within the network where an improvement of the infrastructure is expected to be highly cost efficient. Indications are given how to determine possible improvement measures. Then, if needed, the cost of these measures can be compared to the potential savings in accident costs in order to determine the benefit-cost ratio of the measure for the section under review.

The methodology is based on the German "Guidelines for Safety Analysis of Road Networks (ESN)" and the French “User safety on the existing road network (SURE)” approach which were developed further to an internationally applicable framework.

Owing to the background of the authors all the necessary parameters for the application of the described procedures are provided for Germany and France only. However, this document provides all the necessary information to adapt and apply the approach to other European countries. Based on national data the missing parameters shall later be added to the tables by national experts.

1.2 Purpose

European countries are seriously engaged in reducing the number of fatalities and casualties on European roads. In order to reach this aim all aspects of the transport system – vehicles, road users, and infrastructure – have to be addressed. Accidents are usually caused by deficits in the way these components work together. Therefore, accident data show the combined influence of all components or where these components do not work together well. For road administrations the difficult task is to assess the infrastructure safety of road sections by accident data isolated from other components in order to determine those sections with highest priority for improvements of the infrastructure.

The purpose of the described approach is

- to determine sections within the road network with a poor safety performance based on accident data and where deficits in road infrastructure have to be suspected and
- to rank the sections by potential savings in accident costs in order to provide a priority list of sections to be treated by road administrations.

After that, the following tasks are to analyse the accident structure of the sections in order to detect abnormal accident patterns which can lead to possible improvement measures, and finally to offer the possibility to compare the costs of improvement measures to the potential savings in accident costs to rank measures by their benefit-cost ratio.

Network Safety Management differs from Safety Inspections. The relationship between Network Safety Management and Black Spot Management aimed at local improvements can differ from one country to another. According to the organisation of those responsible for road safety in each country, Network Safety Management can be either understood as a comprehensive process including Black Spot Management or as a complementary process to other procedures. Nevertheless, Network Safety Management is not intended to take the place of a general assessment methodology, e.g. as conducted within a transport infrastructure plan. In a general economic cost-benefit analysis among other aspects like travel time revenues or pollution costs, road safety impacts have to be considered, too. Beside road safety a large variety of economic, financial, social, and environmental impacts should be assessed.

1.3 Scope of application

Although, a safety analysis of the entire road network is desirable, application has to be limited to those parts of the network where the necessary data (accidents and infrastructure) is available. Therefore, this paper concentrates on networks outside built-up areas, e.g. motorways and (two-lane) rural roads. Nevertheless, the procedures are composed in a way that the scope of application can be widened to the same extent that more data becomes available. Therefore, the user himself has to decide which part of the network and which accident information he is able to include. At a first stage the application of the procedures may cover only parts of the national road network and fatal and serious injury accidents.

1.4 Structure of the methodology

The Network Safety Management can be structured as follows:

1. *Network-wide statistical analysis of accident data (chap. 2)*:
   Identification and ranking of the sections to address in priority relying on the analysis of the accident data of the last three (up to five) years and in terms of efficiency as regards accident reduction.

2. *Detailed analysis of worst performing sections (chap. 3):*
   Determination of accident inducing factors of the infrastructure and development of possible countermeasures.

3. *Priority ranking of measures (chap. 4):*
   Assessment of the efficiency of the countermeasures and possibly estimation of potential savings in accident costs which could be compared with costs for countermeasures in order to rank measures by their priority.

While step 1 is described in detail in chapter 2, for steps 2 and 3 indications are given only. These tasks have to be undertaken on the basis of procedures similar to those within the Black Spot Management.

2 Network-wide analysis of accident data

2.1 Number and severity of accidents, period under review

Due to different legal basis and reporting practice the extent and coverage of national accident databases differs widely within the European countries. Furthermore, accident categorisations show many inconsistencies between the various countries. Therefore, international accident comparisons (e.g. IRTAD) usually concentrate on a restricted accident population which describes the common basis. Best reported accident data are available for motorways and the national road network. The more severe the accident the better is the information. Damage-only accidents mostly do not form part of national accident databases.

For a ranking of road sections to be treated by road administrations within a country or any other lower administrative unit (e.g. region or district) the evaluation should base on all the available information in order to reach best possible statistical results. Consequently, for the network under review reliable data of less severe accidents should be included in the analysis if available.

For the described methodology the following accident categories can be distinguished:

SI Severe personal injury accident (accidents with fatalities and seriously injured persons)
MI Minor personal injury accident (accidents involving persons suffering minor injuries)
SD Severe material damage-only accident

Differing definitions of these accident categories within the European countries do not affect the methodology but have to be considered when adapting the parameters to the national situation.

Sufficiently large accident numbers must be available for analysis of the existing road safety (cf. 2.2). If not, statistical tests should be conducted (cf. 2.7). Therefore, the calculation must at least include the severe personal injury accidents SI. The number of fatal accidents is often very low, especially on short sections with low traffic volumes, and the ranking would not provide statistically reliable results.

It is also possible to distinguish between fatal accidents and accidents with seriously injured persons. The consequence is that the ranking is mainly influenced by fatal accidents which are statistically rare and therefore less stable. In that case, statistical tests are highly recommended.

In addition, it must be aimed at having as long a period under review as possible. The accident occurrence should, however, be as up-to-date as possible so that influences resulting from general trends and changes do not have an impact on the informative value. Experience has shown that a period of 3 to 5 years should be scheduled for an appropriate consideration of the severe injury accidents (accidents with fatalities or seriously injured persons) within the framework of road network evaluations.

2.2 Section length

Road sections should be as long as possible so that the safety evaluation leads to informative results.

Basically, there are two possible ways of dividing the road into sections:

- dividing the road into sections on the basis of the network structure or
- dividing the road into sections on the basis of the accident occurrence.

Dividing the road into sections on the basis of the network structure is appropriate if

- a visualisation of the accident occurrence on the road network is not available or
- the accident occurrence is to be analysed in interaction with other influencing parameters (e.g. road improvement standard, accessibility, traffic) in the road network.

  Each section must then be characterised by more or less the same traffic volume, the same cross section and the same type of environment (cross town link or rural section). It is recommended that the sections should be around 10 km (at least 3 km) long.

Dividing the road into sections on the basis of the accident occurrence is appropriate if

- a visualisation of the accident occurrence (three-year maps of the severe injury accidents) is available (see Figure 1) and
- no other section demarcations are required on the basis of a joint consideration of various influencing parameters.

A section with A(SI) = 3 or less is to be combined with a neighbouring section.

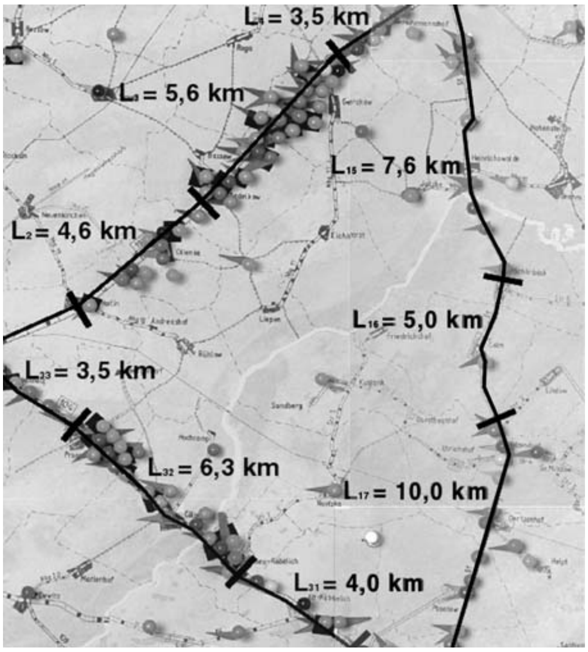

Figure 1: Dividing the road into sections on the basis of the accident occurrence (3-year accident type map of the severe injury accidents)

2.3 Accident costs

When analysing accidents A of different categories c together, the numbers of accidents shall be weighted by the accident severity. Accident costs AC are, therefore, used to describe the combined effect of number and severity of the accidents.

It is well known that differing approaches are applied in the European countries to estimate accident costs. As long as these national accident cost values are used only to determine a ranking of road sections within a country the results are not affected by the different accident cost estimation approaches. They just play a role when calculating the benefit-cost ratio of possible improvements of the infrastructure which has to be done based on national construction costs, too. Consequently, the same methodology is applicable if the required parameters are adapted to the national situation as follows:

Mean costs per accident MCA have to be calculated as a function of the accident category c and the road type for each country. These values represent the structure of injuries (e.g. the number of fatalities, seriously injured and slightly injured persons in 100 accidents of the category under review) and are, therefore, strongly affected by differences in category definitions, too. For each road section within the network the accident costs AC of each category c are calculated then by multiplying the number of accidents A(c) with the mean cost per accident MCA(c):

- **Accident cost AC** [€]

$$AC(SI) = A(SI) \cdot MCA(SI)^{*}$$

$$AC(SI + MI + SD) = A(SI) \cdot MCA(SI) + A(MI) \cdot MCA(MI) + A(SD) \cdot MCA(SD) \quad (1)$$

where

A(c) Number of accidents of a specific accident category c in $t \geq 3$ years [A]

MCA(c) Mean cost per accident as a function of accident category c (Table 1) [€/A]

Table 1: Mean cost per accident MCA(c) in €/A for evaluation of the current accident situation as a function of accident category (c) and road category for different European countries

Mean cost per accident [€/A]						
	Motorways			Rural roads		
	Accident category					
Country	**SI**	**MI**	**SD**	**SI**	**MI**	**SD**
A**	320.000			290.000		
B**	315.000			285.000		
CH**	340.000			305.000		
D	300.000	31.000	18.500	270.000	18.000	13.000
DK**	335.000			300.000		
E**	245.000			220.000		
F	515.000	36.500	-	550000	40.000	-
FIN**	300.000			270.000		
GB**	300.000			270.000		
GR**	185.000			165.000		
I**	300.000			270.000		
N**	300.000			270.000		
NL**	335.000			300.000		
P**	200.000			180.000		
S**	295.000			265.000		

Price level 2000

Usually the accident costs are related to the period of one year which results in:

- **Annual average accident cost AC_a** [€/year]

$$AC_a(SI) = \frac{A(SI) \cdot MCA(SI)}{t}$$

$$AC_a(SI + MI + SD) = \frac{A(SI) \cdot MCA(SI) + A(MI) \cdot MCA(MI) + A(SD) \cdot MCA(SD)}{t} \quad (2)$$

where

t Period of time under review [years]

2.4 Densities

Accident densities AD respectively accident cost densities ACD describe the average annual number of accidents respectively overall costs incurred to the economy by accidents occurring over a 1 km length of a road section.

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* It is possible to distinguish between fatal and serious injury accidents:
AC(SI) = A(F) · MCA(F) + A(S) · MCA(S)
where
F Fatal accidents
S Accidents with seriously injured persons

** Dummy values derived from German data (cost and casualty structure) by multiplication with factor representing GDP ratio to be updated later based on national data.

The density can be calculated as the ratio of the annual number of accidents respectively accident costs and length of the road section on which the accidents occurred.

- **Accident density AD** [A/(km · a)]

$$AD = \frac{A}{L \cdot t} \tag{3}$$

- **Accident cost density ACD** [1000 €/km · a)]

$$ACD = \frac{AC}{1000 \cdot L \cdot t} = \frac{AC_a}{1000 \cdot L} \tag{4}$$

where

A	Number of accidents in t years	[A]
L	Length of road section	[km]
t	Period of time under review	[years]
AC	Accident cost in t years	[€]
AC_a	Annual average accident cost	[€/year]

The density is thus a measure of the (length-specific) frequency at which accidents have occurred during a specific period over a specific road section.

2.5 Rates

The kilometrage related accident figures of road sections are given by accident rates and accident cost rates.

- **Accident rate AR** A/(10^6 veh · km)]

$$AR = \frac{10^6 \cdot A}{365 \cdot ADT \cdot L \cdot t} = \frac{10^6 \cdot AD}{365 \cdot ADT} \tag{5}$$

where

ADT Average daily traffic in t years [veh/24 h]

- **Accident cost rate ACR** [€/(1000 veh · km)]

$$ACR = \frac{1000 \cdot AC}{365 \cdot ADT \cdot L \cdot t} = \frac{10^6 \cdot ACD}{365 \cdot ADT} \tag{6}$$

Accident rates AR describe the average number of accidents along a road section per 1 million vehicle · kilometres travelled. Accident cost rates ACR describe the corresponding average cost as the result of road accidents which have occurred along this road section per 1000 vehicle · kilometres travelled.

2.6 Safety potentials

To determine road sections with poor safety properties that could be improved by changes in the roadway, its equipment, and traffic operation is an important task of road administrations. As resources are limited, those sections where improvements can be expected to have the highest benefit-cost ratio have to be treated first. Therefore, information is needed on the accident costs per kilometre (or at a given location) and the safety potentials for possible remedial measures.

The safety potential SAPO is defined as the amount of accident costs per kilometre road length (cost density) that could be reduced if a road section would have a best practice design. The higher the safety potential the more societal benefits can be expected from improvements of the road. The safety potential SAPO is calculated as the difference between the current accident cost density of the section ACD within the period under review and the basic accident cost density bACD:

- **Safety potential SAPO** [1000 €/(km · a)]

$$SAPO = ACD - bACD \quad (7)$$

The basic accident cost density bACD represents the anticipated average annual number and severity of road accidents (represented by the accident costs) per kilometre which can be achieved by a best practice design at the given average daily traffic ADT. It can be calculated as the product of basic accident cost rate bACR and average daily traffic ADT:

- **Basic accident cost density bACD** [1000 €/(km · a)]

$$bACD = \frac{bACR \cdot ADT \cdot 365}{10^6} \quad (8)$$

where
bACR Basic accident cost rate (Table 2) [€/(1000 veh · km)]

In ideal circumstances the basic accident cost rate bACR required for determining the safety potential contains no influence of the infrastructure on the accidents any more but represents the accident cost rate caused only by the other two components of the transport system – vehicle and road users. Thus, substantial differences between the basic accident cost rates bACR of the European countries have to be expected in such an extent that they have to be determined separately based on national information. Basically, there are two (three) possible ways of estimating the basic accident cost rate:

- calculation of the accident cost rate for a sample of sections with best practice design or
- using a specific percentile (e.g. 15 %) of the overall distribution of the accident cost rates.

In the second case, the basic accident cost rate bACR should be regularly updated. Nevertheless, a disadvantage of this way is that the safety potential may vary from year to year.

Another possibility would be to use the average accident cost rate. This solution is the simplest one but will only give a ranking of sections but no indication of the safety potential. Furthermore, the average accident cost rate changes from year to year, too.

Table 2: Basic accident cost rates bACR for motorways and rural roads as a function of accident category (c) and road category for different European countries

Basic accident cost rate [€/(1000 veh · km)]				
	Motorways		Rural roads	
	Accident category			
Country	SI	SI+MI+SD	SI	SI+MI+SD
A*	8,2		26	
B*	8,0		25	
CH*	8,7		28	
D	7,6	11	24	28
DK*	8,5		27	
E*	6,2		20	
F	6,0	8,3 (SI+MI)	33	36 (SI+MI)
FIN*	7,7		24	
GB*	7,6		24	
GR*	4,7		15	
I*	7,6		24	
N*	7,7		24	
NL*	8,5		27	
P*	5,1		16	
S*	7,6		24	

Price level 2000

2.7 Statistical tests

Accident data is characterised by variation over time. Therefore, care has to be taken that reliable safety potentials are calculated and not just chance differences. This requires sufficiently large accident numbers per section to be analysed (cf. 2.2). Statistical tests are recommended to prove the reliability of the results when accident number thresholds are not complied with or when severe injury accidents are subdivided into fatal accidents and accidents with seriously injured persons.

The test consists of the comparison of the observed number of accidents A with the expected number of accidents eA of that section and the determination of the importance of the deviation by calculating the confidence interval of the observed values (Poisson law).

- **Expected number of accidents eA** [A]

$$eA = \frac{365 \cdot \overline{AR} \cdot ADT \cdot L \cdot t}{10^6} \tag{9}$$

where

$\overline{AR}$	Average accident rate	A/(10^6 veh · km)]
ADT	Average daily traffic in t years	[veh/24 h]
L	Length of road section	[km]
t	Period of time under review	[years]

* Dummy values derived from German data (cost and casualty structure) by multiplication with factor representing GDP ratio to be updated later based on national data.

2.8 Possibility to include black spots

According to the organisation of those responsible for road safety in each country this methodology allows to incorporate a Black Spot Management in the framework.

In fact, the safety potential of a black spot can be calculated in the same way. A black spot can be considered as a short section. In that case, the statistical tests described in the paragraph above are very important. For further information corresponding national guidelines are available.

2.9 Possibility to aggregate the sections into itineraries

If the analysis aims at the development of coherent safety countermeasures for longer routes or itineraries e.g. in order to increase the readability of a road, it is possible to gather the sections into itineraries after having calculated the individual safety potentials.

The safety potential of an itinerary is equal to the sum of the safety potentials of all the sections which it is composed of. Then, itineraries are ranked instead of sections (cf. 2.10).

2.10 Ranking of sections

Within the network or sub-network under review the accident parameters are calculated according to chapters 2.3 to 2.6 for each section (Table 3).

Table 3: Calculation of accident parameters per section and ranking of sections

Section	ADT	A(SI) A(MI) A(SD)	AD	AR	AC_a	ACD	ACR	bACD	SAPO	Rank

Then, the sections of the road network are ranked on the basis of the magnitude of the safety potential. As a result the ranking of those sections in the road network having a particularly high need for improvement and particularly high improvement potentials is obtained which forms the basis for a detailed study in order to determine possible improvement measures.

The results of the analysis should be presented in diagrams. Figure 2 shows the distribution of safety potentials of the road sections in the network in form of a map. Figure 3 gives an example of a chart showing the road sections with the highest safety potentials within the network under review.

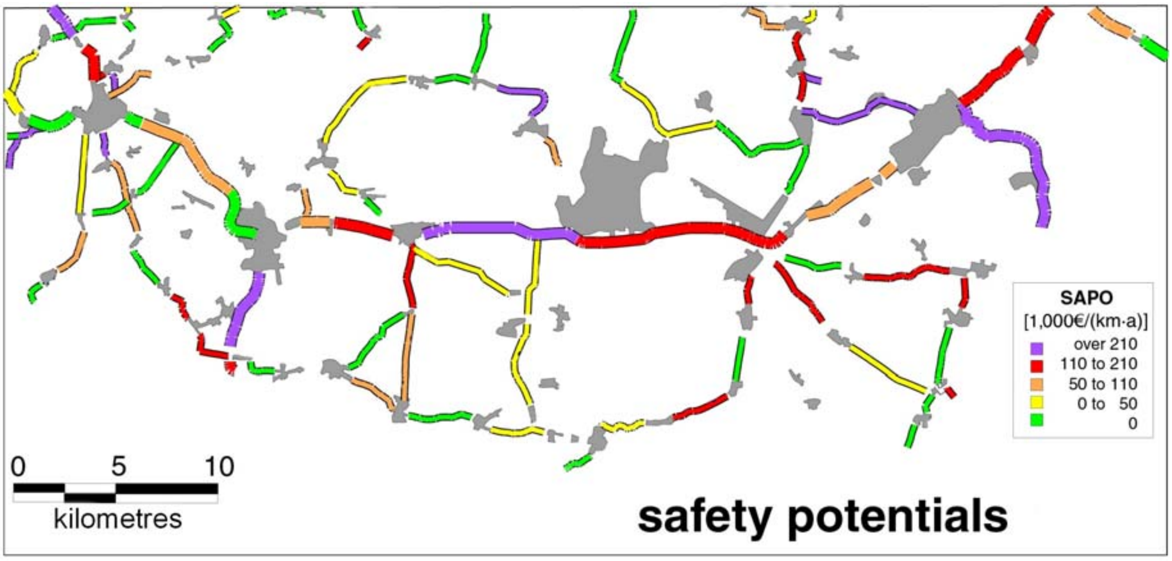

Figure 2: Map of road network showing the distribution of safety potentials (example)

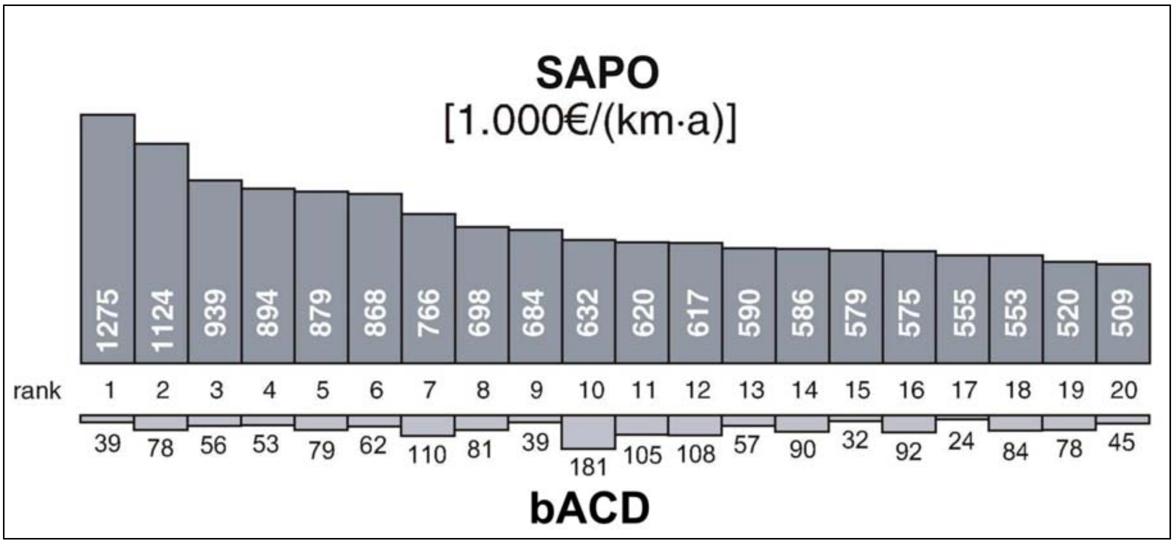

Figure 3: Chart of road sections with the highest safety potentials within the network under review (example)

3 Detailed analysis of individual sections

3.1 Accident structure and accident inducing factors

In order to determine suitable measures for road sections with huge safety potentials, a detailed analysis of the accident structure should be carried out individually for the specific section under review. Therefore, it is advisable to determine conspicuous accident patterns (in the accident structure).

The way the accident structure can be analysed highly depends on the information contained in the national accident statistics. For a comprehensive study it is recommended to include all relevant accident characteristics assigned to the individual accidents. The percentage of each characteristic within the accidents of the section under review shall be compared with the average percentage of this characteristic for all roads of this category in this country or region or a corresponding percentage of best practice design. Table 4 gives an example on how to detect conspicuous accident patterns with focus on the severe accidents.

Table 4: Detection of conspicuous accident patterns (example)

Accident characteristic	A(SI)	Observed percentage	Average/ best practice percentage	Comment
Collisions with fixed obstacle				
Single-vehicle accidents				
Accidents involving pedestrians				
Accidents involving (motor) cycles				
Accidents in curve				
...				
...				
Total		100	**-**	

As a further step a comprehensive analysis of the accidents can be performed similar to the procedures within Black Spot Management. This entails an analysis of detailed accident information such as police reports. The dynamic mechanism of each accident can be identified (driving stage, accident stage, emergency stage, collision stage) and accident factors can be determined.

An accident factor is a state of one of the components of the Driver-Vehicle-Infrastructure system:

- which was necessary but not sufficient for an accident on its own,
- and for which a countermeasure can be determined.

The aim of this analysis is to understand the dysfunctions of the road before implementing countermeasures. It enables planners to adapt solutions to the specific nature of each encountered road and context.

The results of the described analysis should be co-ordinated with the implemented local accident investigation and Black Spot Management.

3.2 Measures for improvement

Based on the detected conspicuous accident patterns and on the comprehensive analysis of individual accidents, suitable measures for the improvement of the road infrastructure shall be derived.

Sustainable improvements in road safety (largely exhausting the safety potentials) can be achieved by structural and supporting operational measures (longer-term measures). Such measures can generally not be implemented in the short term. They require a lead time for planning, financing, adoption of resolutions, and implementation. In many cases, safety deficiencies may also be reduced by immediate action on low-cost measures which can be implemented quickly.

4 Priority ranking of measures

Providing the public with adequate road infrastructure is and has always been an important task of the national states and their representatives. One of the basic conditions is that the infrastructure shall be safe for all road users (motorists and non-motorists) within a country. Thus, an important task for road administrations is to determine road sections with poor safety properties that could be improved by changes in the roadway and its equipment. Since the available funds are always limited, the necessity of the possible improvements and their degree of priority have to be assessed in order to determine a ranking of the most effective projects.

Network Safety Management (NSM) describes a methodology to analyse road networks from the traffic safety point of view and to help the road administrations to detect those sections within the network with the highest safety potential i.e. where an improvement of the infrastructure is expected to be highly cost efficient. Then, suitable measures can be derived from a comprehensive analysis of the accidents. The safety potential and the calculated cost of the measure form the basis for an economic assessment which is usually conducted as a benefit-cost analysis.

Therefore, only the described NSM methodology provides all the necessary information for an objective assessment of road safety and an establishment of a ranking of sections for further analysis and treatment. This way, the limited resources are spent in the best way to improve road safety for the whole society.

Appendix List of abbreviations

A(c)	Number of accidents of accident category c	[A]
AC(c)	Accident costs of accident category c	[€]
AC_a(c)	Annual accident costs of accident category c	[€/a]
ACD(c)	Accident cost density of accident category c	[1000 €/(km · a)]
ACR(c)	Accident cost rate of accident category c	[€/1000 veh · km)]
AD(c)	Accident density of accident category c	[A/(km · a)]
ADT	Average daily traffic	[veh/24 h]
AR(c)	Accident rate of accident category c	[A/(10^6 veh · km)]
bACD(c)	Basic accident cost density of accident category c	[1000 €/(km · a)]
bACR(c)	Basic accident cost rate of accident category c	[€/(1000 veh · km)]
c	Accident category	
SI	Severe injury accidents (accidents with persons seriously injured or killed)	
F	Fatal accidents	
S	Accidents with seriously injured persons	
MI	Minor injury accidents (accidents with slightly injured persons)	
SD	Severe damage-only accidents	
eA(c)	Expected number of accidents of accident category c	[A]
L	Length of section	[km]
MCA	Mean cost per accident	[€/A]
SAPO	Safety potential expressed as accident cost density	[1000 €/(km · a)]
t	Period of time under review	[a]
veh	Motor vehicle	