GENERAL DIRECTORATE OF HIGHWAYS

ROAD IMPROVEMENT AND TRAFFIC SAFETY PROJECT

TRAFFIC SAFETY PROJECT

BLACK SPOT MANUAL

December 2001

SweRoad

Foreword

One of the most cost-effective road safety interventions is to eliminate so-called black spots, that is, to remedy accident-prone locations along the roads. This includes the following steps: identify the black spots, study the problems (diagnosis) at each spot, design suitable countermeasures, estimate their effects, set priorities, implement, and finally, follow up and evaluate the results. This Black Spot Manual includes all these steps.

The Manual (in an earlier version) has been sent for comments to KGM. The comments have been considered in this version.

It must be observed that the Manual has to be improved over time. For example, the estimated reduction factors need to be checked for Turkish conditions and the monetary values for accident and casualty reductions have to be improved. To be able to do this, it is necessary to start a systematic work to follow up the effects of different countermeasures and to compile material about different accident cost components.

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Ankara, December 2001

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Team leader

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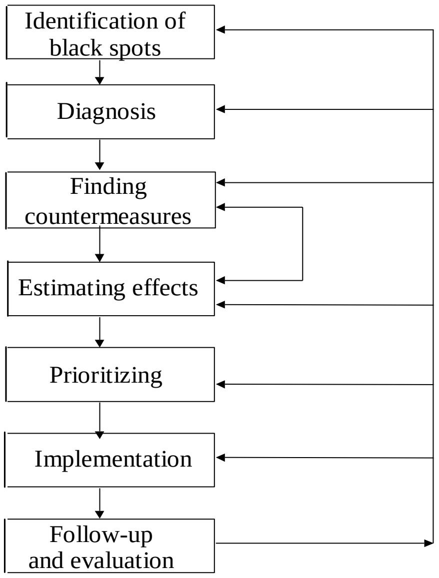
1 Introduction

The process of eliminating or improving accident black spots in a road network is composed of several activities, as illustrated in the following figure.



Identification of black spots is the procedure to locate those spots in the road network that are particularly dangerous, that is, the black spots.

Diagnosis is the process to study what are the problems, the accident contributing factors and the deficiencies for each of the identified black spots.

Finding countermeasures implies a methodical analysis to design suitable countermeasures for each black spot, based on actual problems and deficiencies.

Estimating effects is the process to estimate the safety effects (and if necessary also other effects) and costs of suitable countermeasures.

Prioritizing implies finding the best action plan (or investment program), according to some defined criteria, and based on estimated effects and costs as well as budget restrictions.

Implementation is the actual realization of the prioritized measures included in the action plan (or investment program).

Follow-up and evaluation is the last and very important step, which aim is to assess the actual results (effects and costs).

2 Identification of black spots

2.1 Background

This chapter deals with the procedure for identification of hazardous locations or black spots as they are often called. The procedure described is based on recorded accidents, data about accidents, traffic volumes and vehicle-kilometers. Other methods that can be used as compliments to accident data are not dealt with in this chapter. Examples of such methods are field investigations, conflict studies, questionnaires and interviews, etc.

Identification is a first step in improving road safety at a black spot. It has to be followed by diagnosis of the selected spots, finding countermeasures, estimating effects and costs, prioritizing, implementation and at last follow-up and evaluation. These latter stages are discussed in the following chapters. In this chapter, the identification method used by KGM is scrutinized and some improvements are suggested.

2.2 Used method

The method used by KGM is called Rate – Quality – Control Method. It is a statistical method for identifying black spots. A statistician at the Swedish National Road and Transport Research Institute (Mats Wiklund) has scrutinized the method. The theory part of this paper is based partly on his comments.

The Rate – Quality – Control Method consists of calculating three different parameters for each road section. In Turkey, a road section is defined as one kilometer of road. The three parameters are:

- accident rate,
- accident frequency,
- severity index.

Each of these values is compared with a critical value. Thus the accident rate is compared with one critical value, the accident frequency with another critical value and the severity value with a third critical value. If a certain road section shows higher values than the critical ones for all these three parameters, the section is considered to be a black spot.

2.3 Using more homogeneous groups

The method would be better if junctions were separated from road sections and treated separately. Within “junctions” and “sections” respectively, different groups could be created, groups that are similar regarding geometry and other features. Average accident rate, average accident frequency, and average severity could then be calculated within each group. This would give the method more power to detect black spots.

2.4 Road safety goals and targets

The overall aim for the road safety work is to fulfil the safety goals and targets. The goals do not only decide what resources are needed but also influence which countermeasures should be applied. Goals can, for instance, state that fatalities and severe injuries are to be decreased to or below a certain number. In such case, countermeasures aiming at severe casualties are most important and accidents can be allowed to happen as long as they do not result in severe or fatal injuries. On the other hand, if goals are set for accidents, then the countermeasures should aim at reducing all accidents.

The process of deciding goals and targets is in itself a useful exercise. It increases the safety awareness among involved organizations. So goals and targets are necessary for the future safety work.

If severe accidents are to be reduced, it is necessary to decrease accidents occurring at high speeds and pedestrian accidents, since they often lead to severe consequences. In that case, slight accidents are less interesting, for instance, accidents when a vehicle leaves the roadway where the roadside is flat and without any hazardous objects.

Roundabouts, for example, do not normally decrease the number of accidents, but they drastically reduce the number of severe accidents, at least as long as safe passings are provided for pedestrians and bicyclists.

The goals set should also influence the weighting factors used in the black spot identification. If goals are set for fatal and severe injuries, the weights should be adjusted accordingly.

2.5 Accident rate

In the following sections necessary parts of statistical theory are explained. In addition, comparisons with the formula used by KGM and suggestions for improvements are given.

2.5.1 Statistical theory

A_j Number of accidents on section *j* during a certain time period.

m_j Number of vehicle kilometers in millions on section *j* during the same time period.

$R_j = A_j / m_j$ is the accident rate on section *j* during that time period.

R_c is the critical value for accident rate.

Section *j* is considered to be a black spot, from the accident rate point of view, if:

$R_j > R_c$ where $R_c = \hat{\lambda} + k_\alpha \sqrt{\hat{\lambda}/m_j} - 0.5/m_j$

$\hat{\lambda} = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} m_i} = \frac{1}{n} \sum_{i=1}^{n} \frac{m_i}{m} R_i$ is the estimated average accident rate for sections belonging to the same population. It is assumed that there is *n* such sections.

$-0.5 / m_j$ is a correction for continuity when approximating with the normal distribution.

k_α is a constant that is chosen for the significance test. It is determined from a normal distribution and selected to give a certain significance level α:

α = 0,1% gives $k_\alpha = 2.576$
α = 5 % gives $k_\alpha = 1.645$
α = 10 % gives $k_\alpha = 1.282$

2.5.2 Comparison with the formula used by KGM

In the English translation of the formula used by KGM, the average number of vehicle-kilometers for all sections is used. This is not correct. The number of vehicle- kilometers for the tested section should be used, and not the average. It is not a quality control method if the average is used. It is just a way to get a critical value. It is, however, understandable that KGM uses the average value for vehicle-kilometers. In the US Report "Safety design and operational practices for streets and highways" is said "average exposure of traffic during study". It should be stated more clearly that it is the average over the years for the actual road section that should be used.

KGM also uses "plus" (+) for adding the last term in the equation. It should be "minus" (-) instead.

2.5.3 Suggestions for improvement

$k_\alpha = 1.282$ should be used (see below).

Each kilometer should have its individual value, m_j for vehicle-kilometers.

It should be $-0.5/m_j$ and not $+0.5/m_j$ in the formula.

2.6 Accident frequency

~~2.5.1~~2.6.1 Statistical theory

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A road section is considered to be a black spot, from the accident frequency point of view, if:

$$A_j > A_c, \text{ where } A_c = F_{ave} + k_\alpha \sqrt{F_{ave}/L_j} - 0.5/L_j$$

A_c is the critical value for accident frequency (= number of accidents).

L_j is the length of the road section. Here, L_j is assumed to be 1 km.

F_{ave} is the average accident frequency for all road sections.

~~2.5.2~~2.6.2 Comparison with the formula used by KGM

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In the English translation of the KGM method, it is stated that the average number of vehicle-kilometers should be used. Instead, it should be the length of the road section. If vehicle-kilometers is used, it will give wrong results. Vehicle-kilometers will give a critical value that is lower as soon as the value is more than 1 million vehicle-kilometers. One million vehicle-kilometers corresponds to about 2750 vehicles per day if one year is considered.

~~2.5.3~~2.6.3 Suggestions for improvement

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$k_\alpha = 1.282$ should be used (see below).

It should be road length and not vehicle-kilometers in the formula.

It should be $-0.5/L_j$ and not $+0.5/m_j$ in the formula.

2.7 Accident severity

~~2.5.1~~2.7.1 Statistical theory

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The severity value for road section number *j* is $S_j = I_{f,j} \times 9 + I_{b,j} \times 3 + I_{d,j} \times 1$, or more clearly:

> Severity = number of fatalities (f)*9 + number of injured persons (b)*3 + number of damaged vehicles (d)*1.

This value can be divided by a suitable value. One such value could be the number of accidents. The relative severity value is then $Q_j = S_j / A_j$, which means severity per accident. Here the assumption of Poisson-distribution cannot be used. The average value is estimated with:

$$Q_{ave} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} A_i}$$

And the variance σ^2 is estimated with:

$$\hat{\sigma}^2 = \frac{1}{n-1} \sum_{i=1}^{n} \left(Q_i - Q_{ave}\right)^2 .$$

The road section is considered to be a black spot, from the severity point of view, if:

$Q_j > Q_c$, where the critical value $Q_C = Q_{ave} + k_\alpha \sqrt{\hat{\sigma}^2} - 0.5$.

~~2.5.2~~2.7.2 Comparison with the formula used by KGM

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In the KGM-method, it seems as if the average number of vehicle-kilometers is used also for severity. This is not correct. In addition, the last term is added in the KGM version, not subtracted.

In the translation available to SweRoad there seems to be a mistake in the calculations. S_i is the severity value for one kilometer. It is not the severity value divided by the number of accidents for that kilometer which it should be. Also, S_{ave} is defined as average severity per accident. So, there are different dimensions for S_i and S_{ave}.

On road 100, for instance, the average severity per accident is 7. But the average severity per kilometer is 22, which is 3 times higher. This difference is explained by the fact that there is an average of around 3 accidents per kilometer.

Another possible mistake in the formula is that the variance is estimated to be the square root of the mean. But this is only valid for Poisson distributions. And the weighting means that the severity is not Poisson-distributed. The variance is underestimated if the mean is used.

~~2.5.3~~2.7.3 Comments on the weighting factors

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The purpose of using weights is to put more emphasize on severe accidents than on slight ones. There are several different ways of determining such weights.

One possibility is to use weights based on socio-economic costs. In the SweRoad report "Methods and Values for Appraisal of Traffic Safety Improvements" (May 2001), the following accident costs in million TL (1999 price level) are given:

Accidents		Material cost	Risk value	Total
RURAL AREAS	Fatal accident	13,973	235,959	249,931
	Injury accident	6,741	9,432	16,173
	Property damage	813	0	813
URBAN AREAS	Fatal accident	8,716	161,889	170,605
	Injury accident	3,796	6,865	10,661
	Property damage	286	0	286

If weights are based on values for rural areas this would give the relations 300 for a fatal accident, 20 for an injury accident and 1 for property damage only.

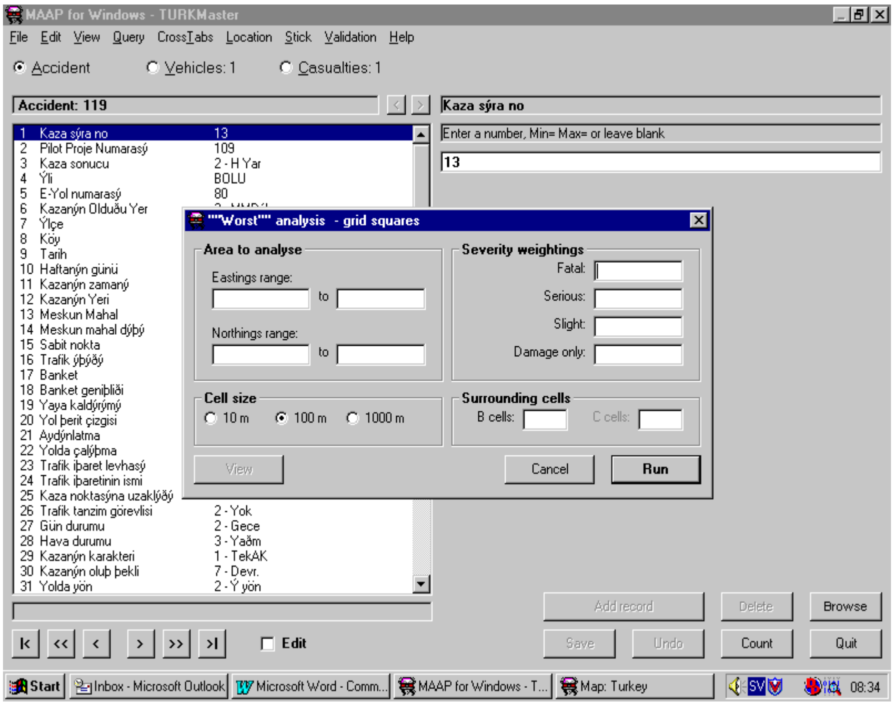
Another way to establish weights would be to base the weights on traffic safety goals if such were stated.

Using weights, however, gives a higher random variation since the randomness is multiplied. The randomness is also higher when the differences in weights are higher. For this reason, SweRoad cannot recommend values that differ as much as 300 to 1. In addition, such weights will be almost equivalent to analyzing fatalities only.

On the other hand, the weights cannot be too similar because then the weights would be of little use. A reasonable compromise between these two extremes is to use the factors 9:3:1 for fatal accidents, injury accidents and damage only accidents.

Compared with the weights used at present by KGM (9 for fatalities, 3 for injuries and 1 for damage vehicles) this means that fatal accidents are weighted instead of fatalities, injury accidents are given weights instead of injuries, and damage only accidents instead of damaged vehicles. These weights can be used until new weighting factors have been estimated and decided.

In the Microcomputer Accident Analysis Package (MAAP) there is a function called "worst". This can be used for selecting the places with the highest numbers of accidents and also with the highest number of weighted accidents. A print-out from this function is shown below. Here can be seen that weighting factors can be given to fatal accidents, serious injury accidents, slight injury accidents and damage only accidents. The area to be analyzed can also be chosen as well as the cell size.



~~2.5.4~~2.7.4 Suggestions for improvement

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If the translation of the KGM method is correct, the formula is wrong and should be corrected. S_i and its average must correspond.

Vehicle-kilometers should not be used in the formula. Number of accidents should be used instead of vehicle-kilometer when "severity per accident" is calculated and section length instead of vehicle-kilometer when "severity per section" is calculated.

$k_\alpha = 1.282$ should be used (see below).

The last term in the formula should be minus and not plus.

Severity per accident should be used instead of total severity for each section.

2.8 All three criteria do not need to be met

As was mentioned under section 2.2, KGM defines a black spot as a road section that shows higher values than the critical ones for all three parameters (accident rate, accident frequency and severity index).

SweRoad would prefer to make three additional lists to be used in the black spot identification procedure, one for each parameter. A reason for this is that sections showing high accident rates do not often have many accidents. And sections having many accidents do not often have high rates. Thus, having a section to satisfy all three criteria means that many sections will not be considered as black spots even if one or two of the parameters fulfil the criteria. There can be many cost-effective countermeasures for a section with a high rate even if the frequency is not high, and vice versa.

The present black spot list based on all three parameters should be used together with the new lists.

The KGM method requires all three criteria to be above its critical value. It can be said that it is a misuse of information to require that all three criteria must be met. It could instead be useful to list all spots where at least one value is above its critical value. This is useful information. When the formula discussed above are corrected, then it will also be very rare to find sections that meet all three criteria.

2.9 Random variation

Accidents normally occur at random. Since it is a random outcome, the actual number of accidents for a road section cannot be trusted to be the true value. The number of accidents differs from one year to another even if nothing has been changed. One spot can have more accidents than another spot during a certain year. But this does not necessarily mean that the first spot is more unsafe that the second one. To handle this randomness, statistical methods can be used. Accidents are normally considered to follow a Poisson-distribution. This means that the number of accidents during a year is an outcome of the statistical process and can be assessed with statistical theory. One very convenient feature with the Poisson-distribution is that the mean value and the variance are the same. Thus only one parameter has to be estimated.

2.10 Choice of confidence level

The purpose of discussing confidence levels in this kind of analysis is to decide the risk of making wrong decisions. Normally, a confidence level of 5 % is used. This means that there is a 5 % risk that a road section is considered a black spot when in fact it is not. Or said in a more understandable way, 5 out of 100 identified black spots are not really black spots. This is called type 1 error in statistical literature. These are spots where the random variations have been unfavorable during the actual period. But why do we accept to have

5 % risk? Why do we include false black spots at all and why do we not at least take a much smaller risk. 1 % or 0.1 % would be better than 5 %!

The reason is that there is another type of error that can be made. Random variations can also be favorable for some spots. A spot can be a black spot, but due to favorable accident outcome during one year, the site is not identified as a black spot. This is a type 2 error in statistical literature. The errors are related in such a way that fewer type 1 errors give more type 2 errors.

If one really wants to be absolutely sure that almost no false black spots are included (by selecting a very low type 1 error) many real black spots will be missed. The level chosen must strike a balance between these two types of errors.

The choice of 5 % by KGM can be questioned and there are arguments for another confidence level, for example, 10 %. The reason is mainly that it is better to risk to include more false black spots and there by get more real black spots.

The first step of the black spot analysis is the identification of the spots. This is a selection procedure that is employed by following certain steps to analyze the identified spots. Then it will be shown if the spots have potential for improvement or not. So the error made with a higher confidence level is that some “unnecessary” work has to be carried out for some spots. By selecting 10 % instead of 5 %, however, no serious errors are made. The only drawback is that the list to work with is extended. But also with a longer list, the work starts from the top. So having a longer list does not necessarily create more work. But, on the other hand, if a real black spot is missed, then a more serious error has been made, which cannot be corrected until new accident data is available for the next period. That is why it is better to have a 10 % confidence level than a 5 % level. Even 20 % is a level that could be considered.

2.11 Using more than one-year data

Using accidents for more than one year is favorable since the random variations to some extent “tend to even out”. If there are three years data and the mean value is three for each year, the mean for the sum of 3 years is 9.

From a purely statistical point of view, it is favorable to have as many accidents as possible. If accidents from more than one year are added, the result would be more accidents. So why not use 3, 5 or even 10 years! There is one important reason, however, apart from the difficulties of storing many years of accident data. There should not be any changes at the spot, not in traffic flows or behavior and not in geometry or surface etc. As changes are frequent, small or big, this limits the size of the time-period. It is often considered that three years is a reasonable period for analysis. Three years is a suitable balance between having a long period for getting many accidents and a short period so that the spot is not changed too much. Spots that are known to have been changed geometrically or in other ways should be treated in a different way. Accidents before and after such changes should not be added.

2.12 Identification without damage only accidents

If damage only accidents are not collected, the numbers for identification will of course be smaller. But the procedures for accident rate and accident frequency will be the same, but based on casualty accidents only. Severity per accident can still be calculated. The weighting factors 9 for a fatal accident and 3 for a injury accident do not have to be changed.

The possibilities to identify black spots will be somewhat reduced if only injury accidents are used compared to when all accidents can be utilized.

2.13 Calculation for road number 100 using the proposed method

Accident data for 1999 for road 100 was chosen to test the method with the suggested changes. It is the part of road 100 that passes through the Pilot Project area. The MAAP database was used to get accident data. The number of accidents was calculated for each kilometer. The number of casualties for each kilometer was calculated separately for fatalities, serious injuries and slight injuries. The number of involved damaged vehicles was calculated for each kilometer. So in all, 3 different tables were made.

Data covers the following kilometers:

Section 100-12	Km 55-82
Section 100-13	Km 00-113
Section 100-14	Km 00-90. Km 90 is in fact the Ilgaz junction and not a road section. It was not treated in a different way than other sections.

The data were copied into Excel sheets where the calculations were made. To this sheet, traffic volumes for 1999 were incorporated.

~~2.11.1~~2.13.1 Accident rate

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Section *j* is a black spot, from the accident rate point of view, if:

$R_j > R_c$ where $R_c = \hat{\lambda} + k_\alpha \sqrt{\hat{\lambda}/m_j} - 0.5/m_j$

$$\hat{\lambda} = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} m_i} = \frac{1}{n}\sum_{i=1}^{n}\frac{m_i}{m}R_i$$

This gives $\hat{\lambda} = 2.0$.

The critical value depends on the number of vehicle kilometers for each section.

Example: $m_j = 1$ gives $R_c = 3.3$ and $m_j = 2$ gives $R_c = 3.0$. A road section that is one kilometer long and has 2 700 passing vehicles per day gives $m_j = 1$ for one year.

~~2.11.2~~2.13.2 Accident frequency

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The total number of accidents is 422. Since there are 133 kilometers, the average accident frequency number will be 3,17 accidents per km. It is assumed that this is the mean value in the Poisson-distribution and the normal approximation is used.

The formula $A_c = F_{ave} + k_\alpha \sqrt{F_{ave}/L_j} - 0.5/L_j$

gives $A_c = 3.17 + 1.282\sqrt{3.17/1} - 0.5/1$

thus $A_c = 4.956524$

Thus, the critical value is 5, which means that kilometers having 5 or more accidents should be included in the black spot list.

2.13.3 Severity

The formula used is based on the severity value per accident. The weighting factors in the calculations below are assumed to be 9:3:1 for fatalities, injuries and involved damaged vehicles respectively. It is, however, for the future recommended to use 9:3:1 for fatal accidents, injury accidents and damage only accidents (see under section 2.7.3).

Section *j* is a black spot, from a severity point of view, if:

$Q_j > Q_c$ and $Q_c = Q_{ave} + k_\alpha \sqrt{\hat{\sigma}^2} - 0.5$

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where $\hat{\sigma}^2$ is the estimated variance of Q_j.

$$\hat{\sigma}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Q_i - Q_{ave})^2$$

$$Q_{ave} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} A_i}$$

Q_{ave} = 7.0 severity value per accident.

and $\hat{\sigma}^2 = 6.4^2$

Q_c = 7.0+1,282*6.4-0.5=14.7

Thus, the critical value is 14.7, which means that kilometers having a severity value **per accident** higher than 14.7 should be included in the list.

Please note that:

- *The average severity value per kilometer is = 22.1 and its variance is* $\hat{\sigma}^2 = 27.9^2$.
- *The function variance in Microsoft Excel uses n in the denominator instead of (n-1). The difference is negligible.*

2.13.4 Identified potential black spots

The kilometers identified as potential black spots are given in tables 1, 2 and 3. The values are printed if the values are above the critical limits. This is equivalent to saying that the index is above 1. Only kilometers where at least one of the criteria is fulfilled are shown.

SECTION 100-12

Km	Number of accidents	Severity value per km	Severity value per accident	Accident rate
58	6			
59	6	61		
60	9			4.33
61			17.00	
64	5			
69	6	87		
71	14	71		6.73
72	6			
73		63	21.00	
74	7	151	21.57	3.37
76	8			3.85
78	5	92	18.40	
79	8			3.85
81			(16.00)	
82	7			3.37

Table 1. Kilometers identified as potential black spots on Section 100-12.

SECTION 100-13

Km	Number of accidents	Severity value per km	Severity value per accident	Accident rate
2	8			3.85
10			(17)	
11	12	93		8.00
12	23	102		15.32

Table 2. Kilometers identified as potential black spots on Section 100-13.

SECTION 100-14

Km	Number of accidents	Severity value per km	Severity value per accident	Accident rate
0	8			5.33
4	5			3.33
5	7	69		4.66
6	17	101		11.33
7	8	77		5.33
14	7	60		4.66
17			(16)	
18	6			4.00
19			(19)	
20	6			4.00
22	9	60		6.00
23	6			4.00
24	9			6.00
29		58	19.33	
32	5			3.33
33			(16)	
37			(17)	
48			(17)	
53	8			5.20
64	5			3.25
65			(38)	
66			(29)	
67	7	116	16.57	4.55
74	5	81	16.2	3.25
81			15	
89	5			3.25
90	8			5.20

Table 3. Kilometers identified as potential black spots on Section 100-14.

The total severity value for a section does not add any additional information. This is why it should be replaced by severity value per accident. In tables 1, 2 and 3, the severity value has been put within brackets if the severity value per accident is high but the number of accidents is low (one or two). It is important to know if the basis for the severity value per accident is only a few accidents.

The calculations above only serve as an example of how to use the method. The method will be improved if junctions are separated from road sections and treated separately. Within junctions and within sections, different groups could be created, groups that are similar regarding geometry and other features. The average accident rate, the average frequency, and the average severity are calculated within each group. This gives the method more power to detect black spots.

2.14 Suggestions in brief

SweRoad suggests that additional lists of potential black spots should be made and include road sections as soon as one parameter is above its critical value.

It is preferable to use three year's data in the calculation process. This is better than calculating values for each year.

The coefficients used should be based on a 10 % confidence level, that is, $k_\alpha = 1.282$.

~~2.11.1~~2.14.1 Accident rate

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- $k_\alpha = 1.282$ should be used.
- Each kilometer should have its individual value m_j for vehicle-kilometers, not the average (m) in the formula.
- It should be $-0.5/m_j$, not + 0.5/*m* in the formula.

~~2.11.2~~2.14.2 Accident frequency

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- $k_\alpha = 1.282$ should be used.
- It should be road length and not vehicle-kilometers in the formula.
- It should be $-0.5/L_j$, not $+0.5/m_j$ in the formula.

2.14.3 Severity value

- $k_\alpha = 1.282$ should be used.
- Severity value per accident should be used.
- Vehicle-kilometers should not be used in the formula. Instead road length or the number of accidents should be used, depending on which of "severity per section" or "severity per accident" that is used.
- The last term in the formula should be minus and not plus.

In addition, SweRoad proposes that severity should be based on weighting of accidents (that is fatal accidents, injury accidents and property damage accidents) instead of persons and vehicles. New weighting factors should be estimated and decided.

2.15 References

- Ezra Hauer, Identification of "sites with promise", Transportation Research Board 75th Annual Meeting, 1996.
- Safety design and operational practices for streets and highways, US Department of Transportation, 1980.
- Mats Wiklund, Comments on Rate Quality Control Method (in Swedish).
- Black spot analysis documents from KGM 2000.

3 Diagnosis

3.1 Criteria in the identification process

The black spot identification process has identified hazardous kilometers based on three different criteria: (i) accident rate, (ii) accident frequency, and (iii) severity value.

In this chapter it will be described how to study the problems, the accident contributing factors and the deficiencies for each identified black spot, the so-called diagnosis. The diagnosis is depending on which of the different criteria that has identified the site as a black spot. Depending on the values, the potential for improvement and the cost-effectiveness can vary.

3.1.1 Accident rate and number of accidents

The table and text below show, for two of the three criteria, how the potential can be:

Accident Rate	**Number of accidents**	
	Many	**Few**
High	A	B
Low	C	D

A. There are many accidents and the accident rate is high. This means a high potential for improvement.

B. There are few accidents but the accident rate is high. Normally this means a potential for improvement. Only cheap countermeasures can be cost-effective, since traffic flow is low.

C. There are many accidents but the accident rate is low. The traffic flow is probably high at this site. There can be a potential for improvement. But normally the situation is such that improving the safety situation can only be achieved with expensive countermeasures. This limits the cost-effectiveness.

D. There are few accidents and the accident rate is low. There is little or no potential for improvement. Countermeasures should be applied only in certain cases. These kilometers are normally not selected in the black spot identification phase.

3.1.2 Identification based on number of accidents or accident rate

The analysis is pretty much the same if the identification is made on the number of accidents or on accident rate. In both cases it is the accidents that have to be analyzed. Rate is a way to identify sites that can have a potential for improvement. But rate consists of accidents divided by traffic volume. The rate can be high and the number of accidents low, if the traffic volume is low.

In theory, the analysis is the same, that is to look for accident patterns. But in practice, this search can be somewhat different. If the rate is based on few accidents, patterns cannot easily be found, simply because several accidents are necessary to form a pattern.

If the rate is high and the number of accidents is low a different approach has to be used. Then accidents have to be analyzed one by one. Site inspections will be more important since it can reveal deficiencies.

3.1.3 Identification based on accident severity

The third criterion is accident severity. Severity is used because it is more important to find countermeasures at sites with serious accidents than at sites with not so serious accidents. First the relevance of the severity value has to be checked. Is it based on few or many accidents? The relevance is greater, of course, if the severity is based on many accidents.

It must, in any case, be checked if there are single vehicle accidents or accidents with more vehicles involved. If there are single vehicle accidents, the severity can depend on dangerous roadsides and then the roadsides should be improved or guardrails erected. If there are multiple vehicles involved, it could be the road design that has to be improved.

3.1.4 Number of accidents and severity

The table and text below show, for two of the three criteria, how the potential can be:

Accident severity	Number of accidents	
	Many	**Few**
High	E	F
Low	G	H

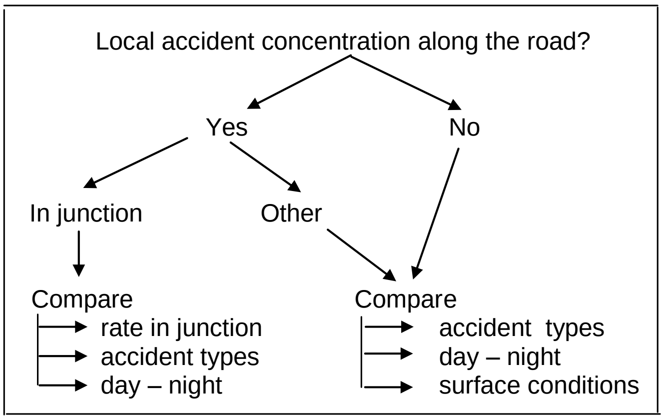
E. There are many accidents and the severity is high. This means a high potential for improvement.
F. There are few accidents but the severity is high. The road design can be dangerous or there are dangerous items on the road or along the sides of the road. It can be possible to find cheap countermeasures.
G. There are many accidents but the severity is low. This spot does not seem to be alarming if safety goals are set to decrease severe accidents. But it is necessary to look at these accidents because they can reveal dangerous situations. It is often possible to find countermeasures.
H. There are few accidents and severity is low. There is little or no potential for improvement. Countermeasures should be applied only in very special cases.

3.2 Location

When “black spot” kilometers have been identified, the next step is locating the accidents within the selected kilometers. The accidents are often, but not always, concentrated to a certain part of the kilometer. It can be a junction, a sharp curve, a bridge or some other dangerous point.

With MAAP this is can be done by using accident mapping. To use mapping is also a good idea in order to make sure that there are no accident clusters that cover the border between two kilometers. If that is the case, cross tables can miss these clusters, since accidents are split up on the two kilometers. But this is more for the identification phase than for the diagnosis phase.

Diagnosis could follow the structure shown in the figure below:



The main aim with the analysis is to search for accident patterns. Patterns that can reveal deficiencies in the situation. The accidents can be split up on a number of specifications to see if there are many accidents of a certain feature, with a certain specification. It can sometimes be difficult to decide what is many or few of a certain features. In such cases, it is useful to know what the "normal" situation is and to compare with that.

In the following section of the report percentages or averages for a number of situations are given. They have been calculated from the Pilot Project (PP) roads for 1999 and 2000. These values are for temporary use only. Revised percentages should be calculated for larger numbers of accidents.

3.3 Yes, there is a local accident concentration

If there is a local accident concentration along the road, it must be clarified if the concentration is in a junction or not. If the concentration is in a junction, there are at least three comparisons that can be made:

- Accident rate can be calculated for the junction.
- Accident types can be compared.
- Day and night accidents can be compared.

~~3.1.1~~3.3.1 Accident rate for junctions

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In the identification phase one criterion is accident rate for the kilometer. If there are safety problems at a junction, the accident rate can be calculated for that junction alone. This gives an idea of the magnitude of the problem and the potential gain with improvements. The accident rate for a junction is different from that for a section. For a section, vehicle-kilometers are calculated. For a junction, this corresponds to the number of vehicles entering the junction. The calculated measure will be accidents per million incoming vehicles. It could be a research project to establish normal rates for different junction types in Turkey.

~~3.1.2~~3.3.2 Accident types for junctions

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The composition of accident types differs depending on the geometry of the junction. The percentages for the PP roads during 1999 and 2000 are shown below.

The numbers are too few to be separated into different junction types. The percentage of vehicles from same direction is higher and the percentage from adjacent directions is lower in 3-leg junctions compared with 4-leg junctions.

Accident Types	Accidents in junctions
Single vehicle	15 %
Vehicles from same direction	39 %
Vehicles from adjacent directions	35 %
Vehicles from opposite directions	6 %
Overtaking	1 %
Pedestrian	1 %
Others	3 %
Total	100 %

~~3.1.3~~3.3.3 Accident types for road sections

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The corresponding percentages for road sections (excluding junctions) are shown below:.

Accident Types	Accidents on road sections
Single vehicle	57 %
Vehicles from same direction	25 %
Vehicles from adjacent directions	2 %
Vehicles from opposite directions	8 %
Overtaking	4 %
Pedestrian	2 %
Others	2 %
Total	100 %

3.3.4 Day-time – night-time

The accident distribution on day and night can be calculated. Normal distribution for accidents is 66 % during day-time, 30 % during night-time and 4 % for dusk and dawn (PP roads).

These average percentages can be used for comparisons. A night percentage higher than 30 can indicate a special problem for night traffic. The percentages are almost the same for junctions and sections, so no separation is needed.

3.3.5 Surface conditions

The accident distribution on surface conditions can be calculated. Normal percentages are: dry surface 63 %, wet 32 %, snowy 3 % and icy 2 %.

Percentages above 32 for wet conditions can indicate a special problem with wet surfaces, for instance, bad friction on wet road. Considerably more than 3 % snowy and 2 % icy accidents indicate that winter maintenance can have good potential, even though such small numbers have to be assessed with care.

3.3.6 Collision types

The accident distribution on collision types can be calculated. Collision types should be used as a compliment to accident types. When the problem is many single vehicle accidents, it can, for instance, be interesting to know if they hit fixed objects or rolled over.

Normal collision types for the PP roads in 1999 and 2000 are shown below:

Collision types	Accidents on road sections	Accidents in junctions
Head on	5 %	1 %
Rear end	21 %	26 %
Nose to side	11 %	49 %
Side to side	2 %	4 %
Roll over	24 %	4 %
Fixed object	13 %	7 %
Pedestrian	2 %	3 %
Others	22 %	6 %
Total	100 %	100 %

3.3.7 Vehicle types

The distribution on vehicle types can be calculated. Vehicle types involved in accidents can be helpful in the diagnosis, especially if trucks are involved in more accidents than the percentages below.

Normal vehicle percentages for the PP roads are shown below. Vehicle types with less than 2 % have been added to "all others".

Vehicle type	Percent
Automobile	60 %
Minibus	4 %
Pick up truck	10 %
Truck	15 %
Bus	5 %
All others	6 %
Total	100 %

3.3.8 Accidents

The distribution of accidents on accident severity can be calculated.

Accident severity for the PP roads for 1999 and 2000 are shown below:

	Fatal accident	Serious injury accident	Slight injury accident	Damage only	Total
Number of accidents	159	203	1096	2033	3491
Percentage of accidents	5 %	6 %	31 %	58 %	100 %

3.3.9 Casualties

The casualties distributed on severity can be calculated.

Casualty severity for the PP roads for 1999 and 2000 are shown below:

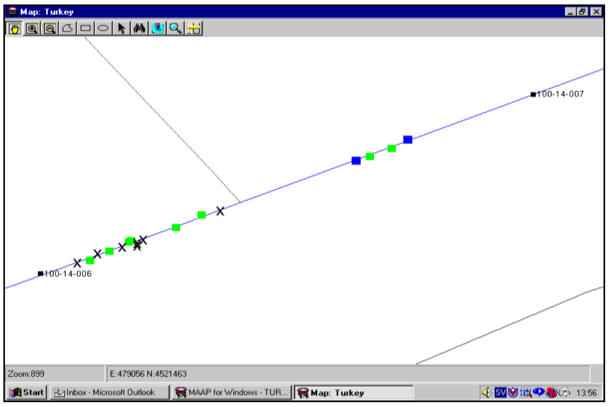
	Fatality	Serious Injury	Slight injury	Total
Number of persons	255	524	3083	3862
Percentage of persons	7 %	13 %	80 %	100 %

3.4 Stick diagram analysis

MAAP can be used for describing different accident details. It is called “stick diagram analysis”. The items can be decided from the items in the form. Below is one example using some important items.

3.5 Example from section 100-14, kilometer 6

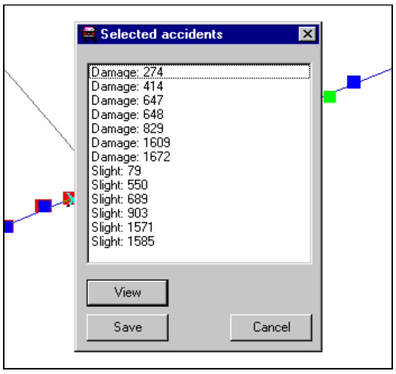
The example below shows the situation for section 100-14, kilometer 6.



This section was identified with 17 accidents, severity value per km 101, and accident rate 11.

The map shows a cluster of 13 accidents at the beginning of kilometer 6. There is another cluster of 4 accidents at about kilometer 6.6.

X represents damage only accidents, blue squares represents serious injury accidents and green squares represents slight injury accidents. If there had been a fatal accident, it would have been represented with a red square.



The 13 accidents can be selected from the map. This is done by using the polygon feature as illustrated in the picture to the left. The selection shows the severity and the identification for these accidents. They are saved and can be used for further analysis. These 13 accidents occurred between 100 and 370 meters. This is in fact in the same curve, which can be seen from the stick diagram analysis described below.

A stick diagram analysis for this cluster of 13 accidents on section 100–14, kilometer 6 is shown in the following table.

Accident number	Meter	Month	No. of casualties	Surface condition	Collision Type	Accident type	Day light condition
79	350	11	2	icy	roll over	Single vehicle	day
274	100	5	0	wet	Other	Single vehicle	day
414	370	8	0	dry	nose to side	Vehicles from opposite directions	day
550	300	11	2	wet	Head on	Vehicles from opposite directions	twilight
647	200	12	0	wet	roll over	Single vehicle	day
648	250	12	0	wet	roll over	Single vehicle	day
689	220	3	3	wet	nose to side	Vehicles from opposite directions	day
829	150	6	0	dry	other	Single vehicle	day
903	225	7	4	wet	other	Single vehicle	day
1571	120	8	1	wet	roll over	Single vehicle	night
1585	200	11	4	wet	roll over	Single vehicle	day
1609	250	11	0	wet	fixed object	Single vehicle	day
1672	250	4	0	wet	roll over	Single vehicle	night

All accidents occurred in a curve where the accidents are located from 100 meters to 370 meters from km 6.

3.5.1 Surface condition

10 accidents out of 13 occurred on wet conditions. This is more than expected and an indication that friction can be low.

3.5.2 Day-time – night-time

Two accidents happened during the night. This does not indicate a night-time problem.

3.5.3 Accident types

The accident types are single vehicle or vehicles from opposite directions, that is, vehicles loosing control and colliding with oncoming vehicles.

3.5.4 Collision types

Collision types indicate that one of the single vehicles collided with a fixed object and 6 rolled over. This shows that the sides of the road should be looked into to check the slopes and what obstacles there are.

3.5.5 Vehicle types

In the table below is shown how information on each vehicle can be included, that is vehicle type and driver age. For an accident with more than one vehicle involved, accident details are reported for each vehicle, thus duplicated when there are two vehicles involved in the accident. Accidents identified as 414, 550 and 689 are accidents with more than one vehicle involved. Please observe that accident severity and number of casualties are defined for the accident and repeated for each vehicle.

Accident Number	Driver age	Vehicle type	Accident severity	No. of casualties
79	37	pick up truck	slight	2
274	40	car	damage only	0
414	38	bus	damage only	0
414	44	bus	damage only	0
550	36	car	slight	2
550	41	truck	slight	2
647	21	car	damage only	0
648	49	car	damage only	0
689	48	minibus	Slight	3
689	46	car	Slight	3
829	53	car	Damage only	0
903	39	car	Slight	4
1571	49	car	Slight	1
1585	28	car	Slight	4
1609	66	car	Damage only	0
1672	42	truck	Damage only	0

3.6 Diagnosis without damage only accidents

The possibility to make a good diagnosis is smaller if damage only accidents are not included. This is obvious since there are fewer accidents to analyze and thus more difficult to detect patterns. But the procedure for diagnosis is the same. Normal numbers and percentages shown above, have to be recalculated and based on injury accidents only.

3.7 Site investigations

A visit to the site is normally a necessary part of the diagnosis. This visit can give a lot of detailed information. The site might also have been visited earlier as part of the identification process. But it can be fruitful to make a new visit at the end of the diagnosis. The diagnosis can have shown patterns that makes a more detailed site investigation useful. It can, for example, give the investigator some new ideas about what to look for.

Checklists can also be used. Appropriate parts of checklists for safety audits can be utilized. See SweRoad's report "Safety Audit Handbook" (December 2001).

The investigator should drive through the site. If it is a junction, he should enter from all directions and test all possible maneuvers. If the problem is wet accidents, he should drive when it is wet. If the problem is night-time accidents, he should drive at night. If there is a pedestrian problem, he should act as a pedestrian, etc.

The investigator observes the site and the traffic situation. It can also be necessary with more objective and long-lasting measurements at the site, such as friction, sight distances, speeds, conflicts, gaps between vehicles and number of pedestrians crossing.

4 Finding countermeasures

4.1 Introduction

The choice of countermeasure should be based on the diagnosis (accident analysis) described in the previous chapter.

When the black spot has been identified, the exact location has been determined, accidents have been analyzed and the problem has been described, this chapter can be used to find a suitable countermeasure and to get some ideas about the expected safety effects. In chapter 5, more details are given about how to estimate the effects.

This chapter is divided into two main parts, Road sections (links) and Junctions (nodes). In each part a number of common problems or accident types are described. For each problem one or more countermeasures are presented together with expected effects. In some cases there are also mentioned some considerations that should be taken into account before the countermeasures are implemented.

4.2 Road sections

4.2.1 Single vehicle accidents

This accident type often implies that drivers lose control and go off the road.

This kind of accident is often related with too high speed regarding the circumstances. The reason for that can be defective visual guidance, like a horizontal curve hidden behind a vertical crest curve, or unexpected situations, like a horizontal curve with a radius smaller than the minimum for the design speed. It can also be related to difference in level between driving-lane and shoulder or insufficient maintenance (potholes or damaged pavement on shoulder or driving-lane).

Countermeasures

Improved signing:	Warning signs, chevrons, delineators, speed-limit signs.
Improved alignment:	Improve the visual guidance, enlarge the curve radius.
Improved skid-resistance:	Rehabilitation of the super-elevation, change of surface texture to increase the friction.
Improved pavement:	Make sure that there is no difference in the level between driving-lanes and shoulders.
Improved roadside area:	Create a safety zone without rigid obstacles in order to reduce severity.
Erect guardrails:	If it is very difficult to improve the roadside area.

Effects
In general, the effects are somewhat uncertain. For accidents in curves the effect is usually higher when there is a single curve on a generally straight road than in curvy sections.

Improved alignment and improved pavement can result in higher speeds that can lead to more severe accidents.

4.2.2 Accidents with vehicles from the same direction

This accident type is usually not very common on road sections between junctions. However, the accident type occurs in hilly sections where the difference in speed between different vehicles is great.

Countermeasures

Add an extra lane:	Construct climbing lanes on hilly sections.
Divided four-lane road:	Construct a divided four-lane road if the traffic volume is high enough to justify this.

Effects

Climbing lanes can be particularly useful where there is a mix of slow and faster traffic, such as on the uphill side of a steep gradient. Advance signing, for example, “Climbing lane 1000 m ahead”, can persuade some drivers to be patient and to wait for a safer opportunity to overtake. In that case, a positive effect can be reached even before the climbing lane.

On long and steep gradients, heavy vehicles are driving slowly even downwards. Provided the traffic volume is high, a four-lane section divided by a barrier or guardrails can be effective to reduce the number of accidents related to hitting from behind. At the same time, head-on collisions will be avoided and accidents related to overtaking will be reduced. On the other hand, the number of single-accidents where vehicles hit the barrier or guardrails will be increased.

Considerations

With climbing lanes a clear definition of where overtaking is permitted, and where it is not, is essential. This should be done with traffic signs and with distinct lane and centerline markings. It is also essential that signs and markings are well maintained, especially at the start and end points.

The start and end points of a divided section has to be chosen in such a way that the visual guidance is clear. It is also important that the end points (terminals) of the barriers and guardrails are safely designed.

4.2.3 Accidents with vehicles from opposite directions

This accident type implies that one of the drivers intersects the centerline without overtaking.

This type of accident can be the result of incorrect position on the road because of deficient road markings or potholes and worn pavement due to bad maintenance. It can also depend on a driver that takes a short cut in a curve.

Countermeasures

Maintenance:	Renew the horizontal markings and/or the pavement.
Widening the road:	Construct paved shoulders, widen the driving-lanes.
Separate the directions:	Install median, concrete barriers or guardrails.

Effects
The horizontal markings should generally be renewed every year. The safety effect of new horizontal markings could be a reduction of accidents if centerlines and edge-lines are renewed at the same time. The speed, however, will usually increase.

Increasing the width up to normal standard has a positive effect on both number and severity of accidents. The effect of widening already existing shoulders is uncertain.

If the directions are separated by a median wide enough to avoid over-running or by a barrier, head-on collisions can be reduced by almost up to 100 %. On the other hand, other types of accidents can increase, such as hitting from behind or single vehicles hitting the barrier. However, the severity is usually lower for those kinds of accidents.

Considerations
The start and end points of a divided section has to be chosen in such a way that the visual guidance is clear. It is also important that the terminals of the barriers and guardrails are safely designed.

4.2.4 Overtaking

Accidents related to overtaking could be between two vehicles in the same direction or between two vehicles in opposite directions.

In both cases, the distance to the oncoming vehicle was too short, either because the sight distance was too short due to a curve or a crest, or because the driver that made the overtaking misjudged the distance to the oncoming vehicle.

Countermeasures

Increase sight distance:	Make sure that sufficient sight distance for overtaking is provided at reasonable intervals along a road section.
Add an extra lane:	Construct climbing lanes on hilly sections.
Divided four-lane road:	Construct a divided four-lane road if the traffic volume is high enough.

Effects
A general improvement of the alignment along a road can reduce the number of accidents substantially, depending on the difference in alignment before and after.

Climbing lanes can be particularly useful where there is a mix of slow and faster traffic such as the uphill side of a steep gradient. Advance signing, for example, “Climbing lane 1000 m ahead”, can persuade some drivers to be patient and to wait for a safer opportunity to overtake. In that case a positive effect can be obtained even before the climbing lane.

Provided the traffic volume and the number of over-takings are high, a four-lane section divided by a barrier or guardrails can be effective to reduce the number of accidents related to overtaking. At the same time, head-on collisions will be avoided. On the other hand, the number of single-accidents, where vehicles hit the barriers or guardrails will probably be increased.

Considerations
With climbing lanes a clear definition of where overtaking is permitted, and where it is not, is essential. This should be done with traffic signs and with distinctive lane and centerline markings. It is also essential that signs and markings are well maintained, especially at the start and end points.

The start and end points of a divided section has to be chosen in such a way that the visual guidance is clear. It is also important that the terminals of the barriers and guardrails are safely designed.

4.3 Junctions

4.3.1 Single vehicle accidents

This accident type could occur when single vehicles continue straight on from the third leg in a T-junction or when single vehicles hit signs or traffic islands in a junction.

Countermeasures

Visibility:	Increase the visibility of the junction, especially from the secondary road approach.
Warning signs:	Install warning signs saying that there is a junction ahead.
Speed limit:	Change the speed limit to 70 km/h or 50 km/h through the junction.
Rumble strips:	Apply rumble strips in order to increase the driver’s attention and to reduce speed.
Lighting:	If there are many accidents during dark hours, install road lighting.

Effects
Traffic islands in the secondary road normally have a small safety effect in four-leg junctions.

A local speed limit through the junction will reduce the number of accidents and also the severity.

Lighting has a double effect. Firstly, it announces the junction in general and secondly, it makes it easier to observe traffic islands and signs as well as other vehicles etc.

4.3.2 Accidents with vehicles from same direction

This accident type could happen when one vehicle hits another from behind, for example, when the first vehicle has slowed down because of a stop or yield sign, traffic signals or turning movements.

Countermeasures

Visibility:	Increase the visibility of the junction in order to make drivers aware of that such actions can be taken by other drivers.
Warning signs:	Install warning signs saying that there is a junction ahead.

Speed limit:	Change the speed limit to 70 km/h or 50 km/h through the junction.
Channelization:	Provide separate lanes for left-turning and/or right-turning vehicles.

Effects
A local speed limit through the junction will reduce the number of accidents and also the severity.

A separate lane for left-turning vehicles has a positive safety effect, especially in 4-leg junctions. A separate lane for right-turning vehicles has normally no safety effect.

Considerations
When a separate lane for left-turning vehicles is used, a median, designed to give shelter for vehicles waiting in the left-turning lane, should be constructed.

4.3.3 Accidents with vehicles from adjacent directions

This type involves accidents between vehicles in the main road and vehicles entering from the secondary road.

Countermeasures

Speed limit:	Reduce the speed limit to 70 km/h or 50 km/h through the junction.
Traffic control:	If there is no regulation, install yield-sign or stop-sign in the approach of the secondary road. If the junction is yield-regulated, change it to stop-regulated.
Signalization:	If there is regulation, install traffic signals.
Visibility:	Make sure that the junction is visible in all approaches and that there is enough sight distance. It is important that there are no billboards, advertisement signs, etc. obstructing the sight from the secondary road towards the main road.
Lighting:	If there are many accidents during dark hours, install road lighting.
Junction design:	Increase the angle between the intersecting roads.
Divide a four-leg junction:	Change a four-leg junction into two three-leg junctions.
Modern roundabout:	If the traffic volume is similar on all approaching roads, consider reconstruction to a “modern” roundabout.
Grade separation:	If the traffic volumes are high, consider grade separation.

Effects
A local speed limit through the junction will reduce the number of accidents and also the severity.

A change from yield to stop regulation is effective in rural areas.

Modern, traffic regulated, signals have a rather good safety effect. Time-regulated signals might increase the number of accidents.

Changing a four-leg junction into two three-leg junctions normally has a good effect on accident severity, especially if the percentage of vehicles from the secondary road is high.

Considerations
The angle between the main road and the secondary road should be close to 90°.

4.3.4 Accidents with vehicles from opposite directions

This type involves mainly accidents with vehicles turning to the left from the main road.

Countermeasures

Channelization:	Separate lane for left-turning.

Effects
Separate lane for left-turning vehicles has a positive safety effect, especially in four-leg junctions.

Considerations
When a separate lane for left-turning vehicles is used, a median, designed to give shelter for vehicles waiting in the left-turning lane, should be constructed.

4.3.5 Accidents with pedestrians

These are normally accidents in junctions between motor vehicles and pedestrians, when the pedestrians are crossing one of the junction legs.

Countermeasures

Marked pedestrian crossing:	Pedestrian crossings marked with vertical signs and horizontal markings.
Channelization:	Install fences to lead the pedestrians to safe crossing locations.
Secure low speed:	Install speed reduction devices, such as rumble-strips, before at-grade pedestrian crossings. In urban areas speed humps can be used.
Signalization:	Traffic signals will separate pedestrians from motor traffic in time. Traffic signals could introduce hazards of a different kind if vehicle speeds are relatively high in the approaches to the crossing. Therefore, approaching traffic must have adequate visibility and time to stop when required.
Grade separation:	If the number of pedestrians and/or the traffic volume is high or if the number of children and elderly is significant, a grade-separated crossing should be considered.

Effects
The effect of marked pedestrian crossings is uncertain. The best effect is achieved if the marked crossing is combined with speed reducing devices.

Grade separation (over- and underpasses) is very effective, if it is used by pedestrians.

Considerations
When a marked pedestrian crossing is provided, the pedestrians could get a false feeling of safety when using it. Therefore, it is essential that the location is visible for the drivers and that a low speed is ensured.

The use of grade-separated crossings is very much depending on the location. The location should be where it is convenient for the pedestrians.

5 Estimating the effects of countermeasures

5.1 Introduction

The basis for prioritizing is to have estimates of the benefits of different proposed countermeasures. Thus it is essential to make forecasts of the accident and injury outcome if a certain measure is applied. These forecasts have to be based on knowledge of the reduction factors of different countermeasures. This knowledge is best built up from research and follow-ups of the results from different places where the measures have been applied. This is a task for future safety research in Turkey.

Building up knowledge will take many years and a reliable common data bank is required. Meanwhile, it is necessary to have some understanding of expected reduction factors. This can be reached by using research and development from other countries and adjust to Turkish conditions and Turkish behavior in traffic.

Applying the same measure at different places can give different results. One reason is that there are not two places that are exactly the same. Another reason is that random fluctuation in the number of accidents and injuries can give different results. One special problem with the randomness is the so-called regression-to-the-mean effect. Without going into details, it is important to remember that normal selection of black spots tends to overestimate the reduction factor. This is explained in chapter 8 Follow-up and evaluation.

The reduction factor estimates given in this chapter are mainly based on a Swedish handbook “Effektkatalog 2000” (Ref. 1) including Swedish experiences, and the Norwegian safety handbook “Trafikksikkerhetshåndbok” (Ref. 2). The latter summarizes knowledge from research reports from many different countries. It is, however, not certain that all these values are applicable to Turkey. There are several reasons why some of the reduction factors could be different in Turkey. However, the given estimates could form a basis for calculating Turkish estimates. For some countermeasures, where Turkish driving behavior differs significantly from European behavior, this has been specially mentioned.

In the chapter:

+ always means increase. This means that the countermeasure is not successful. The number of accidents or casualties is larger than if the countermeasure was not implemented. Sometimes + is strengthened with the word increased, even if this is not strictly correct, increased with +10 %, for instance.

- always means decrease. This means that the countermeasure is successful. The number of accidents or casualties is smaller than if the countermeasure was not implemented. Sometimes - is strengthened with the word decreased, even if this is not strictly correct, decreased with - 10 %, for instance.

Reference is also made to the SweRoad report “Highway design report” (June 2000) and its appendices.

Many of the effect estimates are given as intervals in order to show the variation or uncertainty of the estimates. Different research projects can give different results. The results from research projects are often stated as intervals, due to randomness in accidents.

The intervals can be used as a reminder of the uncertainty involved. It can also be used in such a way that if a countermeasure at one site is thought to be more favorable than at the average site, estimates in the upper end of the interval can be used and vice versa.

Available estimates can refer to different variables, for instance, sometimes fatalities and sometimes fatal accidents. Often there is not detailed information available to separate a reduction factor into fatal accidents and fatalities. For this reason, the same factor can normally be used both for fatalities and fatal accidents. This can also be valid for injuries and injury accidents.

Summary of proposed reduction factors

Countermeasures on sections	Estimated reduction factors			Comments
	Accidents	**Fatalities**	**Injuries**	
Road widening	-20 %	-10 %	-15 %	No reduction in urban areas
Climbing lanes	-25 %	-15 %	-20 %	
Decrease the number of approaches	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Road side delineators	Close to ±0 %	Close to ±0 %	Close to ±0 %	In darkness on roads with bad alignment increase
Road markings	±0 %; -10 %	±0 %; -10 %	±0 %; -10 %	
General speed limits	-10 %; -15 %	-20 %; -30 %	-15 %; -20 %	Depends on decrease in average speed
Lower speed limits during winter	-20 %	-40 %	-30 %	Depends on decrease in average speed
Local speed limits	Decrease	Decrease more than accidents	Decrease more than accidents	
Bridge widening	-40 %	-20 %	-30 %	Not based on empirical data
Side area improvement	±0 %	-20 %; -40 %	-20 %; -40 %	
Guardrails	±0 %	-20 %; -40 %	-20 %; -40 %	
Median barriers	+20 %; +25 %	-15 %; -20 %	-10 %; -15 %	
Vertical alignment	±0 %; -20 %	±0 %; -20 %	±0 %; -20 %	
Increased horizontal curve radius	-5 %; -60 %	-5 %; -60 %	-5 %; -60 %	
Improved signing in horizontal curves	-10 %; -40 %	-10 %; -40 %	-10 %; -40 %	
Super elevation	-10 %; -20 %	-10 %; -20 %	-10 %; -20 %	
Sight distance	-5 %; -15 %	-5 %; -10 %	-5 %; -10 %	
New surface	Around 0 %	Around 0 %	Around 0 %	No reduction

Increased friction	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Decreased rutting	Around ±0 %	Around ±0 %	Around ±0 %	
Decreased unevenness	±0 %; -5 %	±0 %; -5 %	±0 %; -5 %	
Prohibit overtaking	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Variable message signs	-15 %; -20 %	-15 %; -20 %	-15 %; -20 %	
Improved route guidance	Around –2 %	Around –2 %	Around –2 %	

+ means increase, - means decrease, when the countermeasure is applied

Table 4. Estimated reduction factors for countermeasures for road sections

Countermeasures in junctions	Estimated reduction factors			Comments
	Accidents	**Fatalities**	**Injuries**	
Island on the secondary road in 3-leg junction	±0 %	±0 %	±0 %	
Island on the secondary road in 4-leg junction	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Left-turning lane with curbs in 3-leg junction	±0 %; -10 %	±0 %; -10 %	±0 %; -10 %	Closer to –10 % in urban areas and closer to 0 % in rural areas.
Left-turning lane, painted in 3-leg junction	±0 %; -10 %	±0 %; -10 %	±0 %; -10 %	
Left-turning lane, with curbs in 4-leg junction	-10 %	-10 %	-10 %	
Left-turning lane, painted in 4-leg junction	-10 %	-10 %	-10 %	
Right-turning lane	±0 %	±0 %	±0 %	Can increase accidents
Change one 4-leg junction into two 3-leg junctions	±0 %	±0 %; -40 %	±0 %; -40 %	Higher reduction factor when the percentage of vehicles from secondary road is higher
Roundabout	+20 %; -70 %	-50 %; -80 %	±0 %; - 50 %	Can increase accidents in central areas

Modern traffic regulated signals	-15 %; -30 %	-15 %; -30 %	-15 %; -30 %	Time regulated signals increase accidents
Interchange 3-leg	-20 %; -40 %	-40 %; -60 %	-40 %; -60 %	
Interchange 4-leg	-60 %; -70 %	-60 %; -90 %	-60 %; -90 %	
Lighting in junctions	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Change yield to stop in rural areas	-10 %; -15 %	-10 %; -15 %	-10 %; -15 %	
Change yield to stop in urban areas	±0 %; -5 %	±0 %; -5 %	±0 %; -5 %	
Flashing yellow in signal during low traffic hours	+50 %	+50 %	+50 %	
Rumble strips	Decrease	Decrease more than accidents	Decrease more than accidents	Depends on decrease in average speed
Counter measures in railway junctions	-25 %; -70 %	-25 %; -70 %	-25 %; -70 %	

+ means increase, - means decrease, when the countermeasure is applied

Table 5. Estimated reduction factors for countermeasures for junctions.

Improvements for pedestrians and bicyclists	Estimated reduction factors			Comments
	Accidents	**Fatalities**	**Injuries**	
Sidewalks	-5 %; -10 %	-5 %; -10 %	-5 %; -10 %	
Separate bicycle and pedestrian lanes in rural areas	±0%; -5%	±0%; -5%	±0%; -5%	
Separate bicycle and pedestrian lanes in urban areas	Around -4 %	Around -4 %	Around -4 %	
Grade separated pedestrian and bicycle junctions	Around -80 % in pedestrian accidents	Around -80 % in pedestrian fatalities	Around -80 % in pedestrian injuries	Reduction factors depend on the use of separation
Marked pedestrian crossing	+25 %; -20 %	+25 %; -20 %	+25 %; -20 %	Can increase accidents
Bus stop	Small or no reduction factor	Small or no reduction factor	Small or no reduction factor	Small or no reduction factor

+ means increase, - means decrease, when the countermeasure is applied

Table 6. Estimated reduction factors for improvements for pedestrians and bicyclists.

5.3 Road sections

5.3.1 Section types

2-lane roads
Below are shown some average values for rural roads with speed limit 70 km/h from Ref. 1. Accidents with pedestrians and bicyclists are not included.

Road width (m)	Accident rate[x)]	Casualties per accident	Severe casualties per accident	Percentage of damage only accidents (%)
< 5.7	0,456	0,52	0,138	64
5.7-6.6	0,416	0,52	0,138	64
6.7-7.9	0,376	0,52	0,138	64
8-10	0,360	0,52	0,138	64
10.1-11.5	0,336	0,52	0,138	64
11.6 -	0,320	0,52	0,138	64
Motor traffic road	0,248	0,53	0,133	64

[x)] The accident rate is expressed in accidents/10^6 veh-km.

Table 7. Average values used in Sweden for roads with speed limit 70 km/h.

Below are shown corresponding values for rural roads with speed limit 90 km/h from Ref. 1. Accidents with pedestrians and bicyclists are not included.

Road width (m)	Accident rate	Casualties per accident	Severe casualties per accident	Percentage of damage only accidents (%)
< 5.7	0,320	0,63	0,172	61
5.7-6.6	0,296	0,63	0,172	61
6.7-7.9	0,264	0,63	0,172	61
8-10	0,256	0,63	0,172	61
10.1-11.5	0,240	0,63	0,172	61
11.6 -	0,224	0,63	0,172	61
Motor traffic road	0,224	0,58	0,162	61

Table 8. Average values used in Sweden for roads with speed limit 90 km/h.

4-lane roads
Below are shown average values for 4-lane rural roads with speed limit 90 km/h and 110 km/h. Accidents with pedestrians and bicyclists are not included.

Speed limit (km/h)	Accident rate	Casualties per accident	Severe casualties per accident	Percentage of damage only accidents (%)
90	0,224	0,45	0,050	61
110	0,184	0,5	0,090	61

Table 9. Average values used in Sweden for 4-lane roads.

Motorways
Below are shown corresponding values for motorways. Accidents with pedestrians and bicyclists are not included.

Speed limit (km/h)	Accident rate	Casualties per accident	Severe casualties per accident	Percentage of damage only accidents (%)
50	0,560	0,35	0,039	70
70	0,560	0,4	0,044	65
90	0,224	0,45	0,052	61
110	0,184	0,5	0,093	61

Table 10. Average values used in Sweden for motorways.

These data (Table 7 – 10) are from Sweden with a different road safety situation than Turkey. The values cannot directly be used in Turkey. They can probably give a reasonable indication of relative differences between different road widths and types. A research project should be started aiming at estimating corresponding values for Turkish conditions.

5.3.2 Traffic control and equipment for sections

Road widening
A widening from a narrow road to a normal 2-lane road gives according to Ref. 2 the reduction factor that injury accidents decrease with -5 %; -10 % and damage only accidents with -5 %; -25 %.

Ref. 1 gives a -20 % reduction in accidents when widening from 6,5 meter to 13-meter wide rural roads. For urban roads, no reduction is estimated. The percentage reduction is the same for severe and slight accidents.

A wider road decreases the number of accidents in rural roads. The same is not true for urban areas. In urban areas it is more difficult to see any effect at all since there are many junctions and a wider road implies wider junctions, which sometimes make them more dangerous.

Roads with different widths have been compared with respect to their accident rates. This can be useful, but care has to be taken since road width is often correlated with other factors that can also decrease accidents. The alignment can differ, for instance.

In the table below are shown estimates from Ref. 1 indicating a decrease in accident rate for rural roads with increasing width.

Road width before change (m)	**Speed limit 70 km/h**				**Speed limit 90 km/h**			
	Decrease in accident rate with increased width to:				**Decrease in accident rate with increased width to:**			
	7 m	9 m	11 m	≥13 m	7 m	9 m	11 m	≥13 m
6	-13 %	-16 %	-20 %	-25 %	-15 %	-20 %	-30 %	-35 %
7		-5 %	-10 %	-15 %		-10 %	-20 %	-25 %
9			-5 %	-11 %			-10 %	-20 %
11				-5 %				-7 %

Table 11. Estimated reduction factors for road width in Sweden.

The overall estimate for the reduction factor as a result of an average (2-lane roads) widening is -20 % for accidents. Due to increased speed, lower values are estimated for casualties, -10 % for fatalities and -15 % for injuries.

Climbing lanes
Climbing lanes makes it easier to overtake slower vehicles. The longer and steeper a road is, the more useful is a climbing lane. A high number of slow moving vehicles is also an indication of the need for a climbing lane.
A climbing lane effects the traffic situation both before and after the lane. Before, because drivers know that they are going to have overtaking opportunities. This can decrease their frustration and limit the number of dangerous overtaking. After, because the drivers have had the possibility to overtake on a safer section. But there is also a fear that a climbing lane increases the speed and thus injury accidents after the climbing lane.

The end part of a climbing lane has to be given special consideration. Drivers can speed up and make hazardous overtaking, since they know that if they are not overtaking now, they will not get a new opportunity for a long distance.

Ref. 2 estimates overtaking lanes to reduce the number of injury accidents with -20 %. This includes the effect of sections both before and after the climbing lane. For overtaking lanes in both directions (short 4-lane roads) the estimated reduction factor is -40 % for injury accidents.

The estimated reduction factor of climbing lanes is -25 % for accidents. Due to increased speed, it is estimated that fatalities will go down by -15 % and injuries by -20 %.

Decrease the number of approaches
To decrease the number of approaches should decrease the accident risk by around -5 % on high-speed roads and maybe -10 % on roads with 70 km/h speed limit according to Ref. 1.

According to Ref. 2, reducing the number of approaches by 50 % will decrease the number of injury accidents by –25 %; -30 %. These factors are valid when the number of approaches are high.

It is estimated that reducing the number of approaches will decrease the number of injury accidents by -25 %; -30 % for sections with many approaches and where the number of approaches is reduced to 50 %. For sections with few approaches the reduction is less.

Roadside delineators
Research with roadside delineators shows little or no effect on accidents and injury accidents according to Ref. 2. When studying accidents during darkness only, a Finnish study shows a tendency to an increase in injury accidents when roads with bad alignment are equipped with delineators. The increase was not statistically significant. When studying accidents in darkness and during bad surface conditions only, there was a significant accident increase.

Roadside delineators are appreciated by drivers because they increase comfort and make driving easier.

The estimated reduction factor for roadside delineators for accidents, injury accidents and fatal accidents is ±0 %. However, delineators make driving more comfortable and can lead to increased speed.

Road markings
Analysis performed in Ref. 2 shows that the most probable reduction factor of edge markings for injury accidents is -3 %. Estimated reduction in injury accidents for centerline markings is -1 %. Neither -3 % nor -1 % is statistically significant.

In a few studies, the reduction factor has been estimated when a previously unmarked road was marked with both center and edge markings. An analysis of these studies shows a significant decrease of injury accidents by -24 %.

Two research reports compare an unmarked road with a road with center and edge markings and roadside delineators. The results show a significant decrease in injury accidents by -48 %.

Reduction factors largely depend on how drivers adapt to the new situation and change their speed. Road markings are often rather bad in Turkey. The situation is sometimes almost similar to not having any markings at all, that is like marking a previously unmarked road. For this reason it is estimated that road markings have a safety effect of 0 %; -10 %.

It is estimated that the reduction factor for accidents of road markings is: ±0 %: -10 %. Due to increased speed it is estimated that injuries and fatalities decrease less than accidents, probably by ±0 %; -3 %.

Change of general speed limit
Speed limits are not very popular among drivers. Even in a country like Sweden, where the safety awareness is high, 50 % of vehicles in rural areas exceed the limit. Therefore, surveillance is important to keep the number of speeding vehicles down. Automatic speed surveillance using cameras could give substantial results.

One factor making drivers accept speed limits is to have limits in accordance with the geometrical design of the road. Otherwise physical measures may have to be implemented to reduce speed.

There is no doubt, however, that lower speed limits decrease the number of accidents. The most severe accidents decrease more than the number of accidents. Research from many countries has shown this. The amount of the decrease depends on the change in actual speeds. The same change in a speed limit can result in different changes in actual speeds.

Ref. 2 gives the following estimates based on research from different countries. The only conditions included are those where the speed limit has been changed from around 100 km/h (since the maximum speed limit is 90 outside motorways in Turkey). The theoretical calculations are based on the "speed ratio model". The reduction factor of decreased speed can be estimated by using a model for the relationship between accidents and casualties, and average speeds. The model is the following:

- The decrease in injury accidents is supposed to decrease equal to the square of the ratio between speed before and speed after.
- The decrease in serious injury accidents is supposed to decrease equal to the cube of the ratio between speed before and speed after.
- The decrease in fatal accidents is supposed to decrease equal to the ratio between speed before and speed after raised to the power of 4.

This means that the reduction factor of a measure can be estimated by first measuring or estimating the change in average speed.

> *Example:* Speed measurements at a certain site show an average speed of 97 km/h. It is estimated that a changed speed limit (e.g., from 90 to 70 km/h) at this site will decrease average speed to 88 km/h. The estimated reduction factors are:
>
> - Injury accidents $(88/97)^2 = 0.82$, which means $1 – 0.82 = 18$ % decrease.
> - Serious injury accidents $(88/97)^3 = 0.75$, which means $1 – 0.75 = 25$ % decrease.
> - Fatal injury accidents $(88/97)^4 = 0.68$, which means $1 – 0.68 = 32$ % decrease.

Change in speed limit from 100 km/h to 80 km/h. Decrease in actual speed was around 8 km/h.

	Estimated reduction factor	Interval	Theoretical calculations
Fatal accidents	-29 %	(-39 %; -19 %)	-30 %
Injury accidents	-14 %	(-18 %; -10 %)	-16 %
Damage only accidents	-6 %	(-40 %;+17 %)	

Table 12. Estimated reduction factors for 20 km/h decrease in speed limit from 100km/h.

Change in speed limit from 90 km/h to 70 km/h and from 80 km/h to 60 km/h. Decrease in actual speed was around 5-6 km/h.

	Estimated reduction factor	Interval	Theoretical calculations
Fatal accidents	-43 %	(-60 %; -19 %)	-23 %
Injury accidents	-23 %	(-31 %; -14 %)	-13 %
Damage only accidents	-6 %	(-40 %;+17 %)	

Table 13. Estimated reduction factors for 20 km/h decrease in speed limit from 80 - 90 km/h.

Change in speed limit from 70 km/h to 60 km/h and from 60 km/h to 50 km/h. Decrease in actual speed was around 3-4 km/h.

	Estimated reduction factor	Interval	Theoretical calculations
Fatal accidents	-23 %	(-31 %; -14 %)	-19 %
Injury accidents	-9 %	(-10 %; -7 %)	-10 %

Table 14. Estimated reduction factors for 20 km/h decrease in speed limit from 60-70 km/h.

Enforcement is important when a speed limit is changed. In Turkey massive enforcement is necessary if the above mentioned speed and accident reductions would materialize.

The reduction factors of changed speed limit depend on the decrease in speed. Average reduction factors are estimated to be -10 %; -15 % for accidents, -20 %; -30 % for fatalities and -15 %; -20 % for injuries. The reduction factors are based on such changes in speed limit that the actual average speed is decreased by 5-6 km/h.

Time restricted speed limits

Sometimes there is a need for special speed limits during certain times when there are special conditions. Some countries have lower speed limits during the winter and others have special limits on certain "bad roads" during wet surface conditions. Time restricted speed limits are also used around schools where the limits are applicable to, for instance, between 7.00-17.00 on weekdays only.

Special winter limits have been followed up in Finland. The speed limit was decreased from 100 km/h to 80 km/h. Reduction factors are estimated in Ref. 2 to:

	Estimated reduction factor	Interval
All injury accidents	-21 %	(-23 %; -16 %)
Fatal accidents	-40 %	(-58 %; -14 %)

Table 15. Estimated reduction factors for 20 km/h decrease in speed limit during winter in Finland.

For speed limits during wet surface conditions there are no estimates available. The above mention speed-ratio model can be used for estimating the reduction factors.

The estimated reduction factors for time restricted speed limits are -20 % for accidents, -40 % for fatalities and -30 % for injuries when the change in speed limit is 20 km/h.

Local speed limits
Lower speeds give fewer accidents. The number of severe accidents decreases more than the number of accidents. The reduction factor can be estimated using the "speed-ratio model". Calculations of the reduction factor start with deciding the decrease in average speeds (not the decrease in the speed limits). Change in the average speeds is normally much lower than the change in speed limits.

Bridge widening
Sudden decreases in road width are always a potential hazard for accidents. Approaching vehicles can be forced to maneuvers that can be dangerous. They can come too close to oncoming traffic or they can collide with the side barrier. It is important to give the end of the side barrier of a bridge a proper design in order to avoid serious injuries if a vehicle should crash into the terminal.

Pedestrians walking on the bridge could also create hazardous situations if they do not have enough space.

A bridge could also be more slippery than the surrounding road. It is important when estimating the reduction factor of road widening that accidents that happen because of this are excluded from the benefits.

No estimates based on real accident data have been found. It is estimated that the reduction factor is larger than for a normal road widening, maybe double that estimate. If this is assumed, it gives an estimate of -40 % for accidents, -20 % for fatalities and -30% for injuries for the length of the bridge.

Side area improvement
When a vehicle leaves the road it is important that it does not collide with fixed hazardous objects like trees or outcrops of rock. Steep slopes are also dangerous and will be dealt with under the guardrail section. Flattening the side to avoid vehicles from rolling over is also a safety improvement. A possible benefit with flatter sides is that a vehicle that goes off the road will have the possibility to return to the road again. The flattening, however, has become somewhat discussed during the last years. When a vehicle that has gone off tries to come back, the driver sometimes turns the steering wheel so much that when the vehicle changes direction it either rolls over or it passes over the road towards the other ditch. The latter can cause severe accidents if there are oncoming vehicles.

Roadside improvements do not normally decrease the number of accidents but the severity of accidents.

A maximum reduction factor (in Sweden) of side area "softening" is supposed to be -20 % of fatal and seriously injured persons.

Ref. 2 indicates that injury accidents are decreased by -42 % when changing the side-slope from 1:3 to 1:4. A further decrease of -22 % is estimated if improving from 1:4 to 1:6.

It is estimated that the reduction factors for substantial side area improvements are ±0 % for accidents and -20 %; -40 % for fatalities and injuries.

Roadside guardrails
Guardrails are used to prevent a vehicle from leaving the carriageway and the shoulders. It can be used at the roadside to hinder vehicles to go off the road or in the median to prevent collisions with oncoming vehicles. Guardrails on the side are erected where it is dangerous for vehicles to leave the road. The roadsides can be dangerous because the environment is hazardous with trees, rocks or stones or because of steep and high slopes. Guardrails can also be erected where there are pedestrians and bicyclists along the road. This latter purpose is not included in this chapter.

Disadvantages with guardrails could be that they limit the space for pedestrians and bicyclists walking or riding along the road. The end points (terminals) of guardrails can also create severe injuries to vehicle occupants if they are incorrectly designed. Guardrails must also be so soft that a colliding vehicle is not thrown back into the traffic stream, but instead is caught by, and continues along, the guardrail.

Guardrails do not normally decrease the number of accidents. They are more likely to increase the numbers. But if guardrails in a curve, for instance, is equipped with reflectors it could decrease accidents. The main benefit with guardrails is that they decrease accident severity.

Ref. 1 says that a modern guardrail is as good as (if not better than) a flat roadside and a full safety zone.

Ref. 2 gives the following estimates:

	Estimated reduction factor	**Interval**
Fatal accidents	-43%	-48%; -41%
Injury accidents	-52%	-53%; -51%
Damage only accidents	-18%	-22%; -14%

The reduction factors for guardrails are estimated to be approximately the same as for roadside improvements: ±0 % for accidents and -20 %; -40 % for fatalities and injuries.

Median barriers
In Ref. 1 it is estimated that median barriers reduce the number of casualties by -10 %; -15 %. Damage only accidents increase by +20 %; +25 %.

Ref. 2 indicates that median barriers on multi-lane roads decrease the number of fatal accidents by -20 % and the number of injury accidents by -5 %. Damage only accidents increase by +25 %. These results are mainly from USA.

Swedish tests with median barriers on wide two-lane roads show very promising results.

The reduction factors of median barriers are estimated to be +20 %; +25 % for accidents (increase), -15 %; -20 % for fatalities and -10 %; -15 % for injuries.

Vertical alignment
Ref. 2 gives the following estimates of improvements in vertical alignment:

Improved vertical alignment	Estimated decrease in accidents	Interval
from over 70 ‰ to 50 ‰ -70‰	-20 %	-38 %;+1 %
from 50 ‰-70 ‰ to 30 ‰-50 ‰	-10 %	-20 %;±0 %
from 30 ‰-50 ‰ to 20 ‰-30 ‰	-10 %	-15 %; -5 %
from 20 ‰-30 ‰ to 10‰-20 ‰	-7 %	-12 %; -1 %
from 10 ‰-20 ‰ to under 10 ‰	-2 %	-8 %;+6 %

Table 16. Estimated reduction factors for improved vertical alignment.

It is stated that the uphill direction is safer than downhill direction.

The overall reduction factor for an average improvement of vertical alignment is estimated to be ±0 %; -20 % for accidents, fatalities and injuries.

Increased curve radius
The sharper the curve, the higher the sideways friction is needed to keep the vehicle on the road. Accidents happen when the sideways friction is too low and because of high speed or poor road surface. One way to decrease the sideways friction needed is to increase the curve radius.

A driver's behavior depends on how he can foresee the curve. Accidents could happen if the driver is surprised by the sharpness of the curve. It has been shown that a single sharp curve is more dangerous than the same curve surrounded by other sharp curves. This is because the driver knows what to expect when there are many curves. For the same reason, the first sharp curve in a series of curves is more dangerous than the following ones. It is thus important that improvements in curves are made in such a way that accidents are not migrated to the next curve.

Ref. 1 gives the following estimates:

Curve radius before improvement	Curve radius after improvement		
	401- 600 m	601- 800 m	≥ 801 m
≤ 400 m	-25 %	-34 %	-37 %
401-600 m		-12 %	-16 %
601-800 m			-5 %

Table 17. Estimated reduction factors for improved curve radius on roads with speed limit 70 km/h in Sweden.

Curve radius before improvement	Curve radius after improvement				
	201-400 m	**401-600 m**	**601-800 m**	**801-1000 m**	**1001-2000 m**
≤ 200 m	-25 %	-40 %	-48 %	-52 %	-58 %
201-400 m		-20 %	-30 %	-37 %	-45 %
401-600 m			-12 %	-20 %	-30 %
601-800 m				-10 %	-20 %

Table 18. Estimated reduction factors for improved curve radius on roads with speed limit 90 km/h in Sweden

The overall estimated reduction factor for an average improvement of curve radius is -5 %; -60 % for accidents. The highest factor concerns the case when a very sharp curve is improved to an almost straight road. Due to increased speed, the reduction factors for fatalities and injuries are less.

Improved signing in curves
One of the cornerstones of road safety is never to surprise a driver. If there are curves that are sharper than the drivers have reasons to expect, it is wise to have some warning for these curves. It is then advisable to put up signs that improve the driver’s vision of the curve or warns for the curve. It is important that this is done in a consistent way. If other curves with the same geometry are left unattended they could be even more dangerous since drivers’ expectations have changed. It is also important that the signs are visible in darkness.

The reduction factor for background marking signs in curves is estimated to be -20 %; -40 %. Advance warning for curves has been found to decrease the number of injury accidents by -10 %; -30 %. However, the estimates are uncertain. The overall estimated reduction factors are -10 %; -40 % for accidents, fatalities and injuries.

Superelevation
The technical description is that the sideways friction needed depends on vehicle speed, curve radius and superelevation (cross-fall). Unsuitable superelevation could give the result that the sideways friction is too low to keep the vehicle on the road.

The behavioral aspect is that drivers do not adjust speed enough to compensate for unsuitable superelevation. Drivers that are unused to the road may not be aware of the bad superelevation and can be surprised by it. Drivers that are used to the road may know about the bad cross-fall, but tend to take a short cut making it dangerous for oncoming traffic.

No reduction factors based on real accident data have been found. Increased superelevation is much like increasing the curve radius. The reduction factor is estimated to be the same as for a small curve radius increase, -10 %; -20 % for accidents, fatalities and injuries.

Sight distance
In Sweden correction factors are used to adjust for differences in sight distances. Sight distances are classified according to classes 1 to 4, defined in the following table:

Sight class	Percentage of road length with sight distance over 300 meters
1	70–100 %
2	40–70 %
3	20–40 %
4	0–20 %

Table 19. Sight distance classes used in Sweden.

These classes are the basis for correction factors on accident rates. The correction factors are shown in the table below.

Road width (m)	70 km/h				90 km/h			
	Sight distance class				Sight distance class			
	1	2	3	4	1	2	3	4
< 5.7	0.9	0.95	1	1.05	0.95	1	1.05	1.05
5.7-6.6	0.94	0.98	1.04	1.09	0.95	1	1.05	1.05
6.7-7.9	0.99	1.03	1.08	1.14	0.98	1.03	1.08	1.08
8-10	0.99	1.03	1.08	1.14	0.98	1.03	1.08	1.08
10.1-11.5	1	1.05	1.08	1.14	1	1.05	1.08	1.08
11.6 –	1	1.05	1.08	1.14	1	1.05	1.08	1.08

Table 20. Estimated reduction factors for improved sight distance in Sweden.

The factors are used as follows:

On a 5.7-6.6 m wide 70 km/h road, the normal accident rate is multiplied by 0.94 if the sight distance class is 1. It is multiplied by 0.98 if the sight distance class is 2, by 1.04 if the class is 3 and by 1.09 if the class is 4. Reduction factors can easily be calculated from this table.

The reduction factor for a substantially improved sight distance is estimated to be -5 %; -15 % for accidents. Since improved sight distance increases speed, the estimates for fatalities and injuries are lower: -5 %; -10 %.

New surface
Ref. 2 has the following estimates of accidents after resurfacing compared with the old surface:

	Estimated reduction factor	Interval
Injury accidents	+6 %	-12 %; +28 %
Damage only accidents	-3 %	-3 %; +10 %

Table 21. Estimated reduction factors for new surface.

A renewed asphalt surface does not seem to give a statistically significant change in the number of accidents. This holds for both injury accidents and damage only accidents. In some studies, there is a tendency for a small increase in the number of accidents.

The most probable reduction factor for a new surface is ±0 % for accidents, fatalities and injuries.

Increased friction
Increased friction has often been a countermeasure at specific accident-prone sites. The estimates given below are thus subject to regression-to-the-mean-effect and can be overestimating the true reduction factor. This fact is stated in Ref. 2 from where the estimates are taken. The estimates are about injury accidents. Damage only accidents are estimated to decrease with the same percentages.

Friction increase by around 0,1	Accidents on a wet clean surface	Accidents on a dry clean surface	All accidents on a clean surface
From a friction of about 0,5 or lower	-40 % (interval -55 %; -30 %)	±0 % (interval -10 %; +5 %)	-10 % (interval -20 %; -4 %)
From a friction of about 0,6 or lower	-25 % (interval -33 %; -17 %)	±0 % (interval -5 %; +5 %)	-6 % (interval -12 %; -1 %)
From a friction of about 0,7 or lower	-15 % (interval -25 %; -5 %)	±0 % (interval -5 %; +5 %)	-4 % (interval -10 %;+ 3 %)

Table 22. Estimated reduction factors for improved surface friction.

It is estimated that the reduction factor for increased friction is -5 %; -10 % for accidents, fatalities and injuries.

Decreased rutting
Research into the reduction factor of decreased rutting does not seem to indicate any major safety effect. It seems, however, as if higher rut depth can decrease the number of accidents.

The estimated reduction factor for decreased rutting is ±0 % reduction for accidents, fatalities and injuries.

Decreased unevenness
There seems to be a small but positive safety effect of decreased unevenness. This is valid for unevenness values that are not too low. In the research quoted, 95 % of the roads had unevenness under 5,1 mm/m.

The reduction factor for decreased unevenness is estimated to be ±0 %; -5 % for accidents, fatalities and injuries.

Prohibit overtaking
There are no known research results that give the reduction factor of prohibiting overtaking. It cannot be ruled out that prohibiting overtaking can have a positive effect, for instance, in hidden depressions or junctions with bad visibility or other sites with many overtaking accidents. It is important, however, to be consistent and not to use prohibit overtaking too often. Prohibit overtaking is estimated to have a lower reduction factor than a median barrier.

Since a median barrier has a reduction factor of -10 %; -15 %, it is estimated that prohibited overtaking will have a factor of -5 %; -10 %, with the same value for accidents, fatalities and injuries.

Traffic regulation and information with variable message signs (VSM)
VMS have been used at pedestrian crossings etc. and with speed recommendations and road surface and traffic information. Speed reductions by -10 % and up to -30 % decrease in accidents have been the results.

VMS with road surface information have given somewhat lower speed, corresponding to a decreased accident risk by -15 %; -20 %.

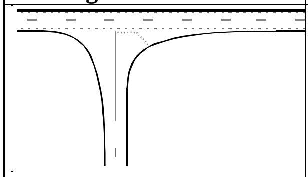
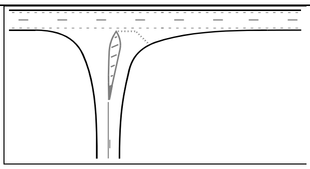
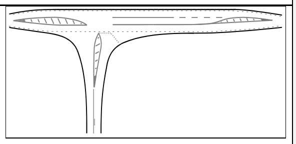
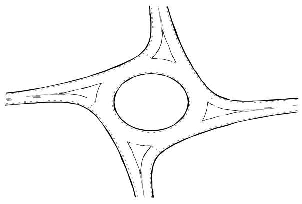
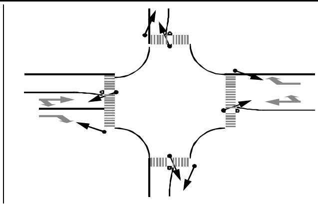
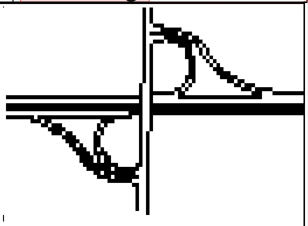
The reduction factor for effective VMSs is estimated to be -15 %; -20 % for accidents, fatalities and injuries.

Improved route guidance
There are no known research results that show the reduction factor of improved route guidance. It is quite possible that clear and unique route guidance has a positive effect on safety. It can avoid sudden brakes when the driver has to change lane or direction at the last second. It can also prevent drivers to take the wrong way, which leads to more vehicle kilometers traveled than necessary.

It is estimated that improved route guidance will have a small reduction factor, around -2 % on accidents, fatalities and injuries.

5.4 Junctions

5.4.1 Junction types

Simple junction. No dividing islands	**Dividing island on secondary road**	**Separate left-turning lane**
		
Modern roundabout	**Signalized junction**	**Interchange**
		

Comment [k2]: One of the pictures have been changed. May need some improvements in the lay out

Below are shown some reduction factor estimates from Ref. 1. The factors are based on the difference in average values for each junction design/type.

3-leg junctions in urban areas				
Junction design/type	**Speed limit 50 km/h**		**Speed limit 70 km/h**	
	Change in number of accidents	Change in number of fatalities and serious injuries	Change in number of accidents	Change in number of fatalities and serious injuries
Dividing islands on the secondary road	0 %	0 %	0 %	0 %
Left-turning lane painted	-5 %	0 %;-5 %	-5 %; -10 %	-5 %
Left-turning lane with curbs	-5 %	0 %; -5 %	-5 %	0 %; -5 %
Modern roundabout	+20 %; -20 %	0 %; -15 %	-10 %; -30 %	-20 %; -40 %
Modern signalization	+25 %; -10 %	+5 %; -20 %	+15 %; -5 %	-10 %; -30 %
Interchange	-30 %; - 40 %	-40 %; -50 %	-20 %; -30 %	-50 %; -60 %

Table 23. Estimated reduction factors for 3-leg junctions in urban areas in Sweden.

3-leg junctions in rural areas				
Junction design/type	**Speed limit 70 km/h**		**Speed limit 90 km/h**	
	Change in number of accidents	Change in number of fatalities and serious injuries	Change in number of accidents	Change in number of fatalities and serious injuries
Dividing islands on the secondary road	0 %	0 %	0 %	0 %
Left-turning lane painted	-10 %; -15 %	-10 %	-10 %; -15 %	-10 %; -15 %
Left-turning lane with curbs	0 %	0 %	0 %	0 %
Modern roundabout	-30 %; -50 %	-40; -60 %	Not recommended	Not recommended
Modern signalization	-10 %; -30 %	-5 %; -20 %	Not recommended	Not recommended
Interchange	-20 %; -30 %	-40 %; -50 %	-20 %; -30 %	-50 %; -60 %

Table 24. Estimated reduction factors for 3-leg junctions in rural areas in Sweden.

When the speed limit is 50 km/h in a rural area, the same reduction factor estimates are used as for 50 km/h in an urban area.

4-leg junctions in urban areas				
Junction design/type	**Speed limit 50 km/h**		**Speed limit 70 km/h**	
	Change in number of accidents	Change in number of fatalities and serious injuries	Change in number of accidents	Change in number of fatalities and serious injuries
Dividing islands on the secondary road	0 %; -5 %	0 %; -5 %	about -5 %	0 %; -5 %
Left-turning lane painted	-5 %; -10 %	0 %; -10 %	about -10 %	about -10 %
Left-turning lane with curbs	-5 %; -10 %	0 %; -10 %	about -10 %	about -10 %
Modern roundabout	+5 %; -40 %	-10 %; -60 %	-30 %; -60 %	-60 %; -80 %
Modern signalization	+20 %; -20 %	-5 %; -50 %	+10 %; -20 %	-40 %; -60 %
Interchange	-60 %; -70 %	-60 %; -70 %	-60 %; -70 %	- 80 %; -90 %

Table 25. Estimated reduction factors for 4-leg junctions in urban areas in Sweden.

4-leg junctions in rural areas				
Junction design/type	**Speed limit 70 km/h**		**Speed limit 90 km/h**	
	Change in number of accidents	Change in number of fatalities and serious injuries	Change in number of accidents	Change in number of fatalities and serious injuries
Dividing islands on the secondary road	about -5 %	- 5 %	about -5 %	-5 %
Left-turning lane painted	about -10 %	about -10 %	about -10 %	about -10 %
Left-turning lane with curbs	about -10 %	about -10 %	about -10 %	about -10 %
Modern roundabout	-40 %; -70 %	-75 %; -85 %	Not recommended	Not Recommended
Modern signalization	-10 %; -40 %	-5 %; -35 %	Not recommended	Not Recommended
Interchange	-60 %; -70 %	-80 %; -90 %	-60 %; -70 %	-80 %; -90 %

Table 26. Estimated reduction factors for 4-leg junctions in rural areas in Sweden.

When the speed limit is 50 km/h in a rural area, the same reduction factor estimates are used as for 50 km/h in an urban area.

The reduction factors stated above are based on average values for each design. There could be many factors that differ between the different types and designs. This means that the whole reduction does not necessarily reflect the design standard. This is one reason why the reduction factors stated above, not necessarily are the same as the reduction factors given later in this chapter. The results from table 23-26 are used as one reference for estimates in this chapter.

Dividing islands on the secondary road

Dividing islands on the secondary road are, especially in 4-leg junctions, successful when the visibility of the junction needs to be improved. Otherwise, it is not regarded as a measure that decreases accidents, especially not in 3-leg junctions.

One good thing with dividing islands is that it allows pedestrians and cyclists to cross the road in two steps, which increases their safety.

Ref. 2 gives the following estimates:

	Estimated reduction factors	**Interval**
T junction		
Injury accidents	+18 %	+5 %; +31 %
X junction		
Injury accidents	-17 %	-41 %; +17 %
Damage only accidents	-34 %	-61 %; +12 %

Table 27. Estimated reduction factors for dividing islands on the secondary road.

The reduction factors for dividing islands on the secondary road for the number of accidents, injuries and fatalities are estimated at -5 %; -10 % in 4-leg junctions and ±0 % in 3-leg junctions.

Separate left-turning lanes
The reduction factors of left-turning lanes are uncertain. Nose-to-tail accidents, when a vehicle turns left from the primary road, is decreased to a large extent. But other accident types can be increased since the junction becomes larger and thus more difficult to overview. This could increase accidents with vehicles crossing or accidents involving other maneuvers.

Installing dividing islands is normally positive since it increases the visibility of the junction for approaching vehicles. The drawback is that an obstacle is placed in the middle of the road. This could cause accidents when drivers do not see the obstacle and lose control when hitting them. This can happen when visibility is poor, in bad weather or darkness. If the junction cannot be lighted, it is important that the visibility of signs and markings is good.

One way to overcome the problem with vehicles losing control is to “paint” the islands instead of using islands with curbs. But painted islands can also create problems. Drivers must be prevented from driving on the painted islands. It is especially important to avoid vehicles from using the left-turning lane as an overtaking opportunity. If this cannot be done by normal traffic rules, it can be necessary to physically prevent it. One solution could be to install road delineators in the islands. They have the benefit to make it difficult to drive there and if a driver does not see them, they are so soft that the driver does not lose control in case of hitting them.

Painted islands are of little value if snow or mud covers the painting or if the painting is worn out.

Ref. 2 gives the following reduction factors for T-junctions:

	Estimated reduction factors	**Interval**
Left-turning lanes with curbs		
Injury accidents	-27 %	-48 %; +3 %
Damage only accidents	+20 %	-18 %; +75 %
Painted left-turning lanes		
Injury accidents	-22 %	-45 %; +11 %
Damage only accidents	-20 %	-49 %; +26 %

Table 28. Estimated reduction factors for left-turning lanes in T-junctions.

It can be noted that all intervals cover 0. This means that it cannot be ruled out that reduction estimates can be 0 %.

Ref. 2 gives the following reduction factors for X junctions:

	Estimated reduction factors	Interval
Left-turning lanes with curbs		
Injury accidents	-4 %	-25 %; +22 %
Damage only accidents	-16 %	-49 %; +38 %
Painted left-turning lanes		
Injury accidents	+28 %	-14 %; +92 %
Damage only accidents	-26 %	-47 %; -2 %

Table 29. Estimated reduction factors for left-turning lanes in X-junctions.

It can also be noted here that all intervals cover 0. This means that it cannot be ruled out that reduction estimates can be 0 %.

Ref. 1 also gives the following reduction factors:

	Painted left-turning lane		Left-turning lane with curbs	
	Urban	**Rural**	**Urban**	**Rural**
T junction	-10%	-15 %	-10%	0%
X junction	-10%	-10%	-10%	-10%

Since the intervals cover 0 % higher weight is given to the factors in Ref. 1. The reduction factor for 3-leg junctions with left-turning lanes with curbs is estimated at ±0 %; -10 %, with the lower value in rural areas. The reduction factor for painted left-turning lanes is estimated at -10 %; -15 %. Since painting has probably less effect in Turkey, the reduction factor for this intervention is decreased to ±0 %; -10 %. In 4-leg junctions, painted and left-turning lanes with curbs are estimated to have the same reduction factor of around -10 %.

With painted left-turning lanes and road delineators erected on the islands, the reduction factors are higher than with painted lanes only.

Separate right-turning lanes
A separate right-turning lane does not normally improve road safety. A separate lane can increase the number of accidents, since the junction becomes wider and thus more difficult to overview. Vehicles passing the vehicle aiming at turning right can be in the “shadow” of the right turning vehicle. This creates dangerous situations if waiting vehicles drive into the junction without seeing the hidden vehicle.

The estimated reduction factor for right-turning lanes is ±0 % for accidents, injuries and fatalities.

Modern roundabouts
Modern roundabouts have several advantages from a safety point of view. If correctly designed they decrease vehicle speeds, which is beneficial for safety. A roundabout also creates one-way traffic, which simplifies for the drivers. This also implies that left-turning in front of oncoming vehicles is eliminated. One-way traffic also simplifies for the

approaching vehicle, since the driver only has vehicles coming from one direction to consider when entering the roundabout.

Vehicles are conflicting at small angles in a roundabout. So, if there is a collision, the collision forces are small. This means that the risk of severe accidents is low when there is an accident.

Ref. 2 gives the following estimates:

	Estimated reduction factors	Interval
T junction		
Injury accidents	-27 %	-40 %; -12 %
Damage only accidents	+52 %	+29 %; +78 %
X junction		
Injury accidents	-35 %	-46 %; -23 %
Damage only accidents	+43 %	+37 %; +50 %

Table 30. Estimated reduction factors for roundabouts.

The estimates are based on the situation where approaching vehicles have to yield for traffic already in the junction.

Ref. 2 indicates that the number of injury accidents will decrease by -25 %; -35 %. This result comes from both junctions that previously were signalized and junctions that previously were regulated by yield signs.

The reduction factors for accidents cover a large interval. It happens that the number of accidents increases after the construction of a roundabout. However, severe accidents generally decrease substantially. Therefore, modern roundabouts are one of the best countermeasures for decreasing severe accidents in junctions.

It is estimated that the reduction factors for modern roundabouts are +20 %; -70 % for accidents, -50 %; -80 % for fatalities and ±0 %; -50 % for injuries.

Changing one 4-leg junction into two 3-leg junctions
There are two reasons why transforming one 4-leg junction into two 3-leg junctions decrease the accidents even if some vehicles have to pass through two junctions:

- The accident rate in a 3-leg junction is less than half of the rate in a corresponding 4-leg junction. This is mainly because it is easier to get an overview of the junction.
- The numbers of points where vehicles can have conflicting crossing movements are 3 in a 3-leg junction but 16 in a 4-leg junction.

Ref. 2 gives the following estimates:

	Percentage of vehicles from secondary road			
	< 15 %	**15 %; 30 %**	**> 30 %**	**All**
Injury accidents	+35 %	-25 %	-33 %	-20 %
Damage only accidents	+15 %	± 0 %	+3 %	+3 %

Table 31. Estimated reduction factors for changing one 4-leg junction into two 3-leg junctions.

The reduction factor of changing from one 4-leg junction to two 3-leg junctions is estimated to be around ±0 % for accidents, and ±0 %; -40 % for fatalities and injuries. The reduction factor increases with the percentage of vehicles coming from the secondary road.

Signalization
Ref. 2 gives the following estimates:

	Estimated reduction factors	Interval
T junction		
Injury accidents	-15 %	-25 %; -5 %
Damage only accidents	-15 %	-40 %; +15 %
X junction		
Injury accidents	-30 %	-35 %; -25 %
Damage only accidents	-35 %	-45 %; -25 %

Table 32. Estimated reduction factors for signalization.

Estimating factors from Ref. 1 is given in tables 23-26.

Installing modern traffic signals in a junction is estimated to give an average reduction factor of -30 % for accidents, injuries and fatalities in 4-leg junctions, and -15 % in 3-leg junctions. Traffic signals can, however, increase the number of accidents if installed in junctions where the percentage of vehicles coming from the secondary road is low. It is assumed that the signal is traffic regulated. Time regulated signals are not advisable. They do normally increase the number of accidents.

Violating red light in signalized junctions is more common in Turkey than in the countries where the reduction factor estimates are coming from. This could imply that the reduction factors would be lower in Turkey.

Grade-separated interchange
Grade-separated interchanges are together with modern roundabouts the safest types of junctions. There are, however, certain things that have to be remembered. When a vehicle has left the primary road and arrives at the crossing with the secondary road, this normally at-grade junction can become dangerous. So, it is necessary to have a design that approaching vehicles are not driving too fast. It is also important to try to design approaches in such a way that vehicles do not enter the primary road in the wrong direction.

Ref. 2 estimates the reduction factor of an interchange to be -50 % (interval -57%; -46%). Ref. 1 estimates the reduction factor on accidents to be lower than -50 % in 3-leg junctions and higher than -50 % in 4-leg junctions. The decrease in severe accidents is estimated to be higher than the decrease in all accidents.

The reduction factors for interchanges are estimated to be:

	Accidents	Fatalities	Injuries
Interchange 3-leg	-20 %; -40 %	-40 %; -60 %	-40 %; -60 %
Interchange 4-leg	-60 %; -70 %	-60 %; -90 %	-60 %; -90 %

5.4.2 Traffic control and equipment in junctions

Stop or yield

To use stop signs in a junction is a way of simplifying for the driver. If he follows the intention with the stop, his driving task could be split up in several steps. He drives to the line and stops there. The next step is to look around and decide to start. The third step is to start.

With the yield sign the driver has to do all these things simultaneously, which could be difficult. Especially older drivers sometimes have problems with junctions.
One drawback with too much use of mandatory stop is that it can dilute the acceptance and thus the positive safety effect.

In Ref. 1 the estimated reduction factors on accident reductions are:

	Estimated reduction factor
Change from yield to stop in rural areas	-10 %; -15 %
Change from yield to stop in urban areas	±0 %; -5 %

Table 33. Estimated reduction factors for change from yield to stop in Sweden.

In Ref. 2 the following estimates are given for injury accidents when changing from yield to stop:

	Estimated reduction factor	Interval
T junctions	-19 %	(-38 %;+7 %)
X junctions	-35 %	(-44 %; -25 %)

Table 34. Estimated reduction factors for change from yield to stop.

The estimates given by Ref. 2 may be influenced by regression-to-the-mean effects, because it is not likely that stop will have higher effect than signalization.

The reduction factors for changing from yield to stop regulation are estimated to be around 10 % for accidents, injuries and fatalities in T-junctions and around 15 % in X-junctions in rural areas. The reduction factors are less in urban areas.

Change from stop to yield on the other hand is estimated to increase the number of injury accidents by +39 % (interval +19 %; +62 %).

Changing to four-way stop has been shown to reduce the number of accidents by -45 % in USA and Canada.

Lighting in a junction
Lighting in a junction decreases the number of night-time accidents and thus all accidents. The reduction factor is higher when traffic on the secondary roads is higher. Lighting is also more necessary where there are many pedestrians.

The reduction factor for lighting in a junction is estimated to be -20 %; -40 % of night-time accidents, corresponding to -5 %; -10 % of all accidents, fatal accidents and injury accidents. Where there are many vulnerable road users, the decrease of fatalities and injuries could be higher.

Flashing yellow
When a traffic signal is changed to flashing yellow during low-traffic hours, the number of injury accidents is estimated to increase by +50 % (interval -7 %; +165 %) according to Ref. 2. Flashing yellow is also against the Vienna Convention.

It is estimated that flashing yellow during low-traffic hours will increase accidents, fatalities and injuries by about +50 %.

Rumble strips
Rumble strips consist of a number of painted strips across the road. The aim is to create vibrations and noise so that the driver is alerted. This is also supposed to make him decrease his speed.

Rumble strips can be used before junctions, pedestrian crossings, curves or other sites where increased alertness and speed adjustments are wanted.

The reduction factor of decreased speed can be evaluated by using the same model for the relationship between accidents and injuries and average speeds as was explained under section “Change of general speed limit”. The model is the following:

- The decrease in injury accidents is supposed to decrease equal to the square of the ratio between speed before and speed after.
- The decrease in serious injury accidents is supposed to decrease equal to the cube of the ratio between speed before and speed after.
- The decrease in fatal accidents is supposed to decrease equal to the ratio between speed before and speed after raised to the power of 4.

This means that the reduction factor of a measure could be estimated by first measuring or estimating the change in average speed.

Example: Speed measurements at a certain site show an average speed of 55 km/h. It is estimated that applying rumble strips at this site will decrease average speed to 50 km/h. The estimated reduction factors are:

- Injury accidents $(50/55)^2 = 0.83$, which means 1-0.83 = 17 % decrease
- Serious injury accidents $(50/55)^3 = 0.75$, which means 1-0.75 = 25 % decrease
- Fatal injury accidents $(50/55)^4 = 0.68$, which means 1-0.68 = 32 % decrease

It is estimated that rumble strips in front of a junction decrease the number of injury accidents by -30 % (interval -40 %; -25 %) in the junction, and damage only accidents by -25 % (interval -45 %; -5 %). Fatalities are reduced more, around -40 %.

5.4.3 Railway junctions

Ref. 2 summarizes estimated reduction factors from different studies. Most of the studies are from USA with the designs, traffic rules and road user behavior that are prevalent in that country. Estimated reduction factors are given in the table below.

Measure	Estimated reduction factor	Interval
Mark the junction with X-signs, when previously there were no safety devices	-25 %	-45 %; -5 %
Light and sound signal where there previously were only an X-sign	-50 %	-55 %; -45 %
Install barriers where light and sound signal already existed	-45 %	-55 %; -35 %
Install barriers where signs already existed	-67 %	-75 %; -55 %
Increase the sight distances	-44 %	-68 %; -5 %

Table 35. Estimated reduction factors for railway junctions.

Swedish research shows a significant increase in safety when installing half barriers in junctions where previously only light and sound systems were used. It was also seen that it is dangerous when the road and the railway are running parallel before the junction. Other measures have been to increase the visibility with the light signal in a gantry above the junction. In a junction where the sun was standing low at some times, the light signal was combined with lights on the road surface.

Reduction factors for different types of measures are given in the table above.

5.5 Improvements for pedestrians and bicyclists

Sidewalks on urban roads
Sidewalks on urban roads decrease the number of injury accidents for bicyclists by -30 % and pedestrians by -5 %, but the number of injury accidents with motor vehicles increases by +16 % according to Ref. 2. This means that all injury accidents will decrease by -7 % (interval: -13 %; -1 %).

The reduction factor for sidewalks is estimated to be -5 %; -10 % for accidents, fatalities and injuries.

Separated bicycle and pedestrian lanes in rural areas
Pedestrian and bicycle lanes in rural areas are normally separated from motor traffic lanes. Ref. 2 says that a separate pedestrian and bicycle lane does not necessarily decrease accidents in rural areas. The estimated reduction factor is ±0 % (interval -10 %; +11 %). Ref 1refers to some research reports that indicate a positive effect.

The estimated reduction factor for separate bicycle and pedestrian lanes (in rural areas) is ±0 %; -5 % for accidents, fatalities and injuries.

This result is a little surprising, but one explanation is that the numbers of pedestrians and bicyclists may have increased after the improvement. Another possible explanation could be that all pedestrians and bicyclists do not use the new lane and it becomes more dangerous for those who do not use the new lane. Motor vehicles could also have increased speed and do not expect vulnerable road users in “their lanes”.

Separated bicycle and pedestrian lanes in urban areas
Pedestrian and bicycle lanes in urban areas can be separated from motor vehicle traffic by curbstones. Ref. 2 shows that constructing a separate pedestrian and bicycle lane in urban areas decreases the number of injury accidents.

The estimated reduction factor for separate bicycle and pedestrian lanes (in urban areas) is -4 % (interval: -7 %; -1 %) for accidents, fatalities and injuries.

The lane is separated from motor vehicle traffic by curbs. Even painted pedestrian and bicycle lanes have turned out to be effective.

Grade-separated pedestrian and bicycle junctions
Building a grade-separated junction is estimated to decrease the number of injury accidents by -30 % (interval -44 %; -13 %).

The estimated reduction factor for grade-separated pedestrian and bicycle junctions is -80 % (interval -90 %; -69 %) for pedestrian accidents. The same factors are also used for fatalities and injuries.

These estimates are based on the assumption that over- and underpasses are built and planned in such a way that almost all vulnerable road users really use them. To use the over- or under-pass must not require longer time or longer distance than just crossing the street. Furthermore, there should be no major difference in level. Pedestrians in particular are very sensitive to good designs. There are many examples around the world where grade-separated junctions are not used by pedestrians to the extent anticipated.

Pedestrian crossings
Creating painted and signed pedestrian crossings without curbed islands does not improve safety according to Ref. 2. On the contrary, it increases the number of injury accidents. In

the table below, the estimated reduction factor of different types of pedestrian crossings are given:

Type of Pedestrian crossing	Estimated reduction factor on injury accidents			
	Pedestrian accidents	**Motor vehicle accidents**	**All injury accidents**	**Interval (all injury accidents)**
Painted and signed crossing	+28 %	+20 %	+26 %	+18 %;+35 %
Signalized crossing on a section between junctions	-12 %	-2 %	-7 %	-12 %; -2 %
Signalized junction without separate phase for pedestrians	+8 %	-12 %	-1 %	-7 %;+6 %
Signalized junction with separate phase for pedestrians	-29 %	-18 %	-22 %	-29 %; -14 %
Elevated crossing	-49 %	-33 %	-39 %	-58 %; -10 %
Crossing with islands with curbs	-18 %	-9 %	-13 %	-21 %; -3 %

Table 36. Estimated reduction factors on accidents for pedestrian crossings.

Reduction factors for different types of pedestrian crossings are given in the table above.

Bus stops
There are three types of dangerous situations connected with bus stops:

- The bus decreasing speed and stopping could cause dangerous situations for other vehicles.
- Standing passengers on their way to or from a seat can be injured when the bus is changing direction and accelerating/decelerating.
- The bus or other vehicles can hit pedestrians that are waiting for, or on their way to and from the bus.

The first and the last type are the most dangerous ones. To avoid the last situation it is necessary with good approach roads for pedestrians and good visibility when they go off the bus. It is especially important that they do not cross the road in the “shade” of the bus.

In rural roads there are three types of bus stops:

- The bus stops on the normal roadway.
- The road is widened to give a separate place for the bus (lay-by).
- The road is widened to give a separate place for the bus. This place is separated from the road by an island, sometimes with curbs.

In urban areas there are in principle the same alternatives, but depending on available space, parked vehicles etc. there are some more detailed designs.

Estimated road safety for motor traffic on rural roads	
Bus stop design	**Estimated reduction factor compared with no bus stop**
Bus stop on the road	Small negative reduction factor
Bus bay (separated with curbs)	No reduction factor
Lay-by	No reduction factor

Table 37. Estimated reduction of accidents for different designs of bus stops (mainly on rural roads).

There are no reduction factors based on accident data available. Some indications are given in the table above.

5.6 More than one countermeasure

When more than one countermeasure is implemented at the same site, it is not possible to just add the different reduction factors in order to estimate the resulting total reduction factor for all countermeasures.

Firstly, when one measure has been implemented, the next one will only effect the remaining accidents. In addition, it is possible that the first measure will also reduce the severity of the still occurring accidents and that the reduction factor for the following measure will be less than it generally is because of the effects of the first measure etc.

If, for example, the speed is reduced as the first measure (e.g. by changed speed limit), then the effect of the next measure (e.g., a junction redesign) will be less, because there are fewer accidents to reduce, and the severity of the still remaining accidents and casualties is less. If, on the other hand, some other measure is implemented first, then the effect of a speed reduction could be lower than if it had been implemented first.

So, the reduction factors for the different measures depends on the order of implementation and their respective effects on both accidents and severity (e.g., accident and collision types). In principle, the reduction factors could also be effected by the general safety situation (e.g., concerning seat belt use).

It is, therefore, difficult to give detailed recommendations on how the reduction factors should be reduced if several countermeasures are implemented at the same site. The important thing to remember is that the above mentioned principles have to be considered in order not to overestimate the safety benefits.

6 Prioritizing

6.1 Introduction

The need for black spot improvements are normally much greater than what is possible to implement with available resources. Therefore, a suitable balance must be struck between the needs and what can actually be implemented. When doing this, focus should be on the most suitable safety effects, and the projects should be prioritized accordingly. Sometimes, it may be justified to deviate from this "optimal" order of priority, but having a list of all black spot interventions arranged in order of priority according to their estimated benefits and costs will make decision-makers aware of the reduced benefits and/or increased costs of any deviation.

When planning for the implementation of black spot improvements, it is necessary to decide:

- which black spots should be improved,
- which intervention/design (of different options) should be selected for each site,
- in what order and when the selected interventions should be carried out.

The process to do this is here called "prioritizing". In short, prioritizing implies finding the best projects and the best action plan, according to some defined criteria, based on estimated effects and costs as well as budget restrictions.

Prioritizing is normally made by so-called appraisals. Appraisals and appraisal methods are used to estimate in advance if a proposed project or plan is effective and efficient.

The general principles for project appraisal and setting priorities are explained in SweRoad's report "Methods and values for appraisal of traffic safety improvements" (May 2001). In that report, monetary values for accident and casualty reductions are also given.

6.2 Appraisal methods

For appraisal of black spot improvements, there are, in principle, two main methods (see mentioned report):

- Cost-Benefit Analysis (CBA)
- Cost-Effectiveness Analysis (CEA)

~~6.1.1~~6.2.1 CBA

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CBA implies, in principle, that the sum of all positive effects (benefits) of an investment is set against all negative effects (costs). In order to be able to do so, all effects, positive and negative, have to be expressed in the same kind of unit, money. This means, for example, that accident and casualty reductions, as well as travel time savings and reduced environmental impact etc., have to be given monetary values. The project yielding the best positive effects in relation to the costs should be selected first.

One problem with CBA is that the same amount of money one year does not have the same value another year. This has to be taken into consideration by discounting. The discounting factors depend on the number of years between the actual year and the discount year, and the discount rate. The discounting procedure should not take into account any changes or trends in current prices. It should concern real-term prices only.

This implies that the values of all future benefits and costs have to be discounted and capitalized to a selected discount year and that investment costs also should be capitalized to the same year. The discount year can be different from the year when the intervention is finished and the improved road is re-opened for traffic.

After that, the discounted benefits (B) and the discounted costs (C) have to be compared and analysed. As explained in the mentioned report, the most commonly used indicators are:

- Net Present Values (NPV = B - C)
- Internal Rate of Return (IRR)*
- Benefit/Cost-ratio (BCR = B/C)
- Net Benefit/Cost-ratio (NBCR = (B - C)/C)

In the above mentioned report, it is recommended that the BCR (or NBCR) should be used for setting priorities of black spot improvements. This will result in the highest total NPV in relation to investment costs. A BRC greater than 1 means that the project is profitable and a value lower than 1 indicates that the project causes a loss to society (a NBCR greater than 0 means that it is profitable and a value lower than 0 means that it causes a loss).

A thorough CBA of road investment projects should theoretically include <u>all</u> relevant costs and benefits for society. For road projects, the most common effects and costs are:

- Accident costs
- Travel time costs
- Vehicle operating costs
- Environmental costs
- Investment costs
- Maintenance costs

The costs are obtained by estimating the size of the effects, expressed in some suitable unit, and multiplying this effect by the monetary value. For example, first the number of reduced accidents has to be estimated (see chapter 5) and then this number must be multiplied by the monetary value per accident (see mentioned report). The principle is the same for other effects. For time savings, for instance, the number of saved hours are estimated and then this number is multiplied by the monetary value per hour. Finally, when all effects are estimated and valued, all benefits should be added and the total benefits set against the total costs.

* IRR is the discount rate which equalizes the discounted benefits and the discounted costs (i.e., NPV = 0)

For black spots improvements, which mainly result in safety effects, it could be sufficient to include costs for accident and casualties, investment and changed road maintenance. For high-cost options, however, which also yield substantial other benefits than safety, it is recommended to consider all relevant effects and costs.

It should be mentioned that lack of monetary values and sufficiently detailed models sometimes makes it difficult to to make a full CBA. In such cases so-called engineering estimates could be used to set values to such non-valued effects.

For estimating the BCR, the following general formula can be used:

$$BCR = (B + MC)/IC \qquad \text{(Formula 1)}$$

BCR = Benefit-Cost Ratio
B = discounted value of future accident and casualty reductions (for every year of the economic life-time of the intervention, the estimated reduction in accidents and casualties should be multiplied by the relevant monetary value)
MC = discounted value of changed road maintenance cost because of safety intervention (the value should be added to benefits if the maintenance costs are reduced, and subtracted from the benefits if the costs are increased)
IC = investment cost of safety intervention

The discounting should consider:

- the expected life-time of the intervention,
- the discount rate.

The tax factor should be applied to all costs (see below).

6.2.2 CEA

CEA means that the positive effects, expressed in some suitable unit, for example, number of reduced accidents or casualties, are set aganist the costs expressed in terms of money (i.e., investment costs and substantial changes in road maintenance costs). The project yielding the highest ratio of positive effects compared with the costs should be selected first.

If road safety projects have a special budget, which is solely intended for improving safety, there is, in principle, no need to make a full CBA in order to prioritize between safety measures and other investments. Then it is not necessary to have a monetary value of accidents and casualties. On the other hand, it is normally necessary to have a weighting scale by which different degrees of accident severity can be weighted against each other.

For estimating the cost-effectiveness, the following simplified formula can be used:

ECR = Delta AC/(AYIC + YMC) (Formula 2)

ECR = effectiveness/cost-ratio for the first year
Delta AC = estimated reduction in number of accidents and casualties the first year, weighted according to a scale, e.g., 9 for fatal accidents, 3 for injury accidents and 1 for property damage only accidents. The weighting factors should depend on the safety goals. If the focus is set on fatalities, the weight should be high for these casualties etc.
AYIC = average yearly investment cost of safety intervention (total investment cost divided by the number of years corresponding to the economic life-time of the intervention)
YMC = changed yearly road maintenance cost because of safety intervention

In principle, the tax factor should be applied to all costs (see below).

Theoretically, it would be better to use discounting also for CEA. Then, the following formula could be applied:

ECR* = Delta AC*/ (IC + MC) (Formula 3)

ECR* = effectiveness/cost-ratio (for discounted values)
Delta AC* = discounted number of reduced accidents and casualties for every year during the economic life-time of the intervention. The accidents etc. have to be weighted according to a suitable scale, see above
IC = discounted value of investment cost of intervention
MC = discounted value of changed maintenance cost because of safety intervention (the value should be added to investment costs if the maintenance costs are increased, and subtracted from the investment costs if the maintenance costs are reduced).

6.2.3 Recommended method

Even if the primary goal of a safety budget is to reduce accidents and casualties, it is still of interest to society to see to it that these measures are effective not only from the safety point of view but also from all other aspects. This is especially the case for high-cost options. Therefore, *SweRoad recommends* that CBA (a limited version for low-cost options) should be used for black spot appraisals even if there is a special budget for road safety interventions (this is also what KGM is already doing).

6.2.4 Important parameters and values

According to present KGM analysis, the number of accidents on existing roads are considered to increase directly proportional to **traffic growth** if no safety intervention is implemented. This can be questioned since better cars and better informed drivers will effect the accident outcome without any black spot interventions. In addition, accident statistics shows that there has not been any direct proportionality between traffic growth and increase in casualties. This is especially valid for fatalities. The annual number of fatalities has been almost constant or even reduced, while the number of vehicle-kilometers has increased substantially. Therefore, *SweRoad recommends* not to use the mentioned proportionality, but either to use constant numbers of accidents over time (for the existing road) or to assume more modest increases.

Concerning other effects, such as travel time and environmental impact, traffic growth has of course to be taken into account.

The **discount rate** used for calculations of discounted values of benefits and costs is very important and has a major influence on all results. At present, KGM uses 15 percent, which is a high figure compared with many other countries. This means that short-term interventions are favoured and that long-term investments are difficult to justify. Lowering the discount rate would make substantial increases in the discounted benefits for projects with long life expectancies. *SweRoad recommends* that a lower discount rate should be used for road safety investments (and also for other road investments), for example, in the interval 8-12 percent.

The economic **life-time** (1 year, 5 years, 10 years, etc.) of the interventions has to be estimated in order to make it possible to calculate the discounted values of future benefits and costs, as well as the average annual costs of investment, etc.

In CBA, all **taxes** should be eliminated from costs. However, it is necessary to include some kind of **"tax factor or factors"**, by which all or some of the cost components should be increased (see mentioned report). *SweRoad recommends* that one "tax factor" is used and that this factor is set at 1.17, because KDV is 17 percent at present. In order to get relevant CBA-values, all costs should be multiplied by this factor.

6.2.5 Special questions

Formula (1) and (3) above can give rise to some questions. For example, should in formula (1) the monetary value of accident and casualty reductions increase in real terms over time, or should the same value be applied for all years? Should in formula (3) the estimated number of reduced accidents and casualties be discounted, that is in principle, should a lower value be given today to a life saved in the future than to a similar life saved this year?

These questions have to be discussed further. Awaiting such discussions, *SweRoad recommends* KGM to use the same monetary accident and casualty values in real terms for all years during the economic life-time, and that the number of reduced accidents and casualties for each year are discounted by the normally used discount rate.

6.3 Proposed procedure for KGM

Theoretically, to give correct answers to all the questions mentioned under introduction, prioritizing has to be carried out in one major effort in which all questions, "which black spots, which intervention/design, what implementation order and when", are treated. This, however, would be rather complicated. Therefore, SweRoad proposes the following somewhat simplified procedure:

1. Identify the black spots (see chapter 2).
2. Study the problems and deficiencies for each identified black spot (see chapter 3).
3. Find suitable countermeasure(s) for each spot (see chapter 4). For each spot there should be at least one “low-cost alternative” and one “higher-cost alternative”.
4. Estimate safety effects, costs of investment and changed maintenance costs, etc. for all potential countermeasures (see chapter 5). If the countermeasure is a high-cost option, all relevant effects and costs should be estimated.
5. Set monetary values to accident and casualty reductions (and if necessary to other relevant effects), decide on suitable life-time of interventions, discount rate and “tax factors”, etc.
6. Estimate BCRs for each alternative intervention/design for all black spots.
7. Select the alternative with the highest BCR for each spot.
8. Arrange in falling order of magnitude of BCR.
9. Define the budget limit and determine which black spots could be included in a first draft action plan.
10. Determine the BCR for the last included black spot (the one with the lowest accepted BCR) within the budget frame.
11. Check if any high-cost alternatives for the included black spots yield higher marginal BCR than the BCR obtained for the last included spot (step 10). If this is the case, replace the low-cost alternatives for those spots with the more efficient solutions. Change the order (step 8).
12. Check 9 to 11 again until there are no high-cost alternatives yielding higher marginal BCRs than the BCR for the last included black spot.
13. Consider regional aspects in order to obtain a suitable balance in allocations between KGM regions.
14. Compile the final plan for implementation of the improvements.

If CEA is used the principle will be as follows:

1-4. Same as above.
5. Establish a weighting scale for fatalities, injuries and property damage only accidents.
6. Estimate the Effectiveness/Cost Ratio (ECR) between benefits expressed in number of saved lives, injuries and accidents, and investment costs, adjusted for changed maintenance costs and tax factors.
7. Select the alternative with the highest ECR for each spot.
8. Arrange in falling order of magnitude of ECR.
9. Define the budget limit and determine which black spots should be included in the first draft action plan.
10. Determine the ERC for the last included black spot (the one with the lowest accepted ECR) within the budget frame.
11. Check if any high-cost alternatives for the included black spots yield higher marginal ECR than the ECR obtained for the last included spot (step 10). If this is the case, replace the low-cost alternatives for those spots with the more cost-effective solutions. Change the order (step 8).
12. Check 9 to 11 again until there are no high-cost alternatives yielding higher marginal ECRs than the ECR for the last included black spot.
13. Consider regional aspects in order to obtain a suitable balance in allocations between KGM regions.

14. Compile the final plan for implementation of the improvements.
Before implementing the plan (see chapter 7), a detailed program for follow-up and evaluation should be developed and implemented (see chapter 8).

The above proposed procedure gives answers to **"which black spots should be improved"** and **"which intervention/design should be selected for each site".**

The described method and steps will in principle lead to an "optimal" allocation of funds. If it is considered to be too difficult to follow the outlined steps, it could be possible to separate the black spots into sub-groups, allocate a certain budget to each group, and then prioritize within each of these sub-groups. The groups could, for example, be based on road sections versus junctions.

When there are **different alternatives for each site**, it should be considered that low-cost alternatives in most cases tend to give higher BCRs that higher-cost alternatives. As there are normally many black spots in need of funds for improvement, the leading principle should be to use low-cost alternatives for all sites in order to be able to eliminate as many black spots as possible. This principle will normally yield the highest total NPV within a certain budget frame. The only case when a more costly alternative should be used is when the marginal BCR for the more expensive alternative exceeds the BRC for the best alternative use of funds for other sites.

To consider **regional aspects** is difficult. The priority list obtained after step 12 is theoretically the "best". It will yield the best safety improvement in relation to the cost. On the other hand, it is perhaps necessary to consider the need to allocate some resources to every region. The principle for this should be decided in advance. One key to such a distribution could be the number of accidents on state roads in each region. Other keys could be road length and/or vehicle-kilometers traveled in the region. A simple method would be firstly to allocate a certain, limited amount of funds to all regions and then distribute the remaining (major) part according to the priority list.

In some cases the listed black spots can also be **included in a road rehabilitation program**. In such cases it has to be checked if the black spots should be deleted from the black spot list or if they should be improved to a limited extent awaiting the more extensive improvement through the rehabilitation program.

Comment [I3]: pr

Concerning the question **"in what order and when the selected interventions should be carried out"**, the implementation should be carried out in the order indicated by the list of projects arranged in the order of falling BCRs. However, it must be said that the order of priority and the time for the implementation is normally not that important (yearly budgets and priority lists are assumed). The most important thing is that the most urgent spots are included in the list and that the selected type of intervention/design for each site is suitable to improve safety and that it is cost-effective.

Simplified CB-calculation methods and values have been developed in an Excel sheet that can be used by KGM for black spot appraisals. The Excel sheet is enclosed to the previously mentioned report. *SweRoad recommends* that the proposed methods and values should be used in the short-term perspective.

In the long-term perspective, the proposed methods and values should be checked and also changed, if necessary. This concerns, for example, monetary values for accident and casualty reductions and travel time savings, weighting factors for fatal accidents, injury accidents and property damage only accidents, and “tax factors”.

7 Implementation

The proposed sites should preferably be subject to a road safety audit to ensure that the proposed intervention is a suitable and effective safety measure.

It should also be checked if the reconstruction can be coordinated with other construction works near the site.

The work should be planned so that the construction work is carried out during time-periods when existing traffic is disturbed as little as possible. In addition, the work zone should be arranged in such a way that existing traffic is disturbed as little as possible. In practice this may be conflicting with the safety of the road workers. To ensure their safety, it is often necessary to have harsh restrictions on passing traffic.

All road works are dangerous since all road users are not familiar with the situation. It is therefore necessary to have proper warning for work zones. It is important to give good guidance to road users passing the zone, especially at night and during other conditions when there is bad visibility.

Speed reducing measures must be applied to ensure low speeds for cars passing the site. Changed speed limits are often not enough. Physical measures have to be used. The safety of the workers has to be guaranteed by barriers so that "inattentive" drivers do not hit the workers.

The accident situation must be monitored during the whole construction period to ensure that the situation is under control.

When the work is finalized, another safety audit or inspection should be made before the road is re-opened for traffic.

8 Follow-up and evaluation

8.1 Background

It is necessary to follow-up countermeasures in order to gain knowledge about what has actually happened. The aim is to show if the investment gave good value for money and if the results in safety terms were good or bad.

The purpose of this chapter is to show how follow-up and evaluation could be carried out, to discuss some important aspects and to show possibilities and limitations in the follow-up and evaluation process.

8.2 Planning of follow-up

The follow-up must be planned in advance. This is very important since once the countermeasure is applied, it is too late to make any before measurements on conflicts and speeds, etc. It often happens, that the follow-up is thought of after the site has been changed. Before - after measurements are much better than having to measure afterwards only.

The follow-up should be connected to the problems that are to be solved. Before measurements could have been made as part of the diagnosis. In that case, similar measurements should be repeated in the after situation.

During the after measurements, as many factors as possible should be unchanged. If before measurements cover peak traffic, after measurements should also do so, etc.

8.3 Documentation of countermeasures

The applied countermeasures must be documented in order to make a follow-up possible. The information needed is simple and limited. It is also easy to collect. But it must be observed during the implementation process, because later it will be more difficult to collect and in some cases also impossible. The documentation should contain characteristics of the road and traffic before the site was rebuilt or new equipment installed.

The documentation should contain the dates when the implementation started at the site and when it was finished. This defines the end of the before period and the start of the after period. The implementation period should normally be excluded from the before and after periods.

The implementation period is of interest as it is often a very complicated period from a traffic point of view. There is a danger that this complicated situation could cause accidents. It is therefore useful to analyze accidents during this period for a number of construction sites. The aim is to see if construction works are creating hazards and to study if applied procedures for signs or markings are good enough to give the right information to the road users. This is a different aim than to follow-up the countermeasures. Since this manual is about the latter, the former will not be discussed further in this chapter.

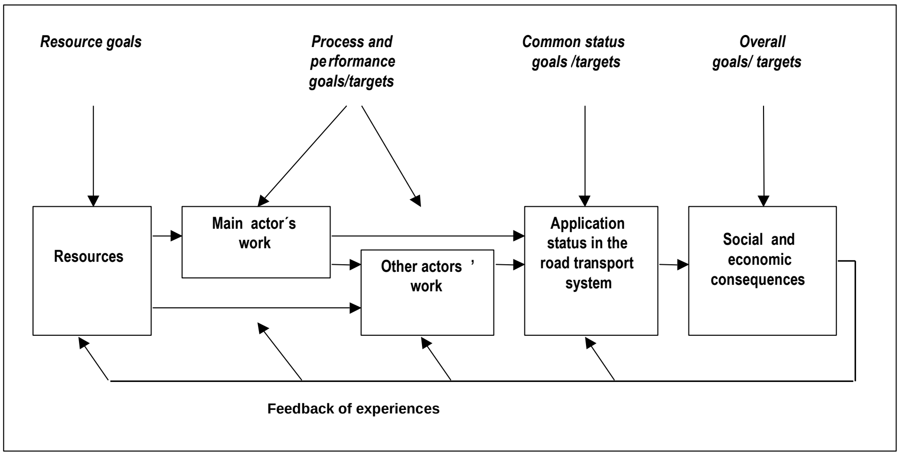
The exact location of the part that is improved shall be stated. From km…. and meter… to km… and meter… If the improvement means that the length of the road is to be changed, the new distances must also be given. The locations decide what part of the road should be followed up.

The countermeasure should be described. The cost of the countermeasure must be specified if the real cost-benefit of the countermeasure should be calculated.

All this information could preferably be stored in a file or a computerized register to be easy to retrieve. This file can also include information on where to find more detailed information, like drawings and photos on the site.

8.4 Target/result-oriented way of planning

The following figure describes an target/result-oriented way of working with road safety.



Follow-up is the basis for the feedback and it should be carried out for all parts in the chain of activities.

For black spot follow-up, implemented countermeasures as well as the last two boxes in the figure above are of special interest.

Common status goals/targets deal with behavioral measurements. This is followed up in the initial monitoring, but can also be used in the long-term evaluation. Overall goals/targets deals with accidents and casualties. This part is most important in the long-term evaluation, but can also be used in the initial monitoring.

8.5 Initial monitoring

It is important to make a follow-up soon after the countermeasure has been applied. The aim is to see if the countermeasure is working as planned and that no new hazards have been created. One purpose is to find out if the road users understand what has been made and if they behave in a suitable way. Also, it is important to see if the problems that were supposed to be solved actually were eliminated or at least reduced.

If there are measurements of speeds, conflicts or other measures of behavior before the countermeasure was applied, these measurements should be repeated in the after-situation.

However, such measurements are often difficult to transform into safety effects. An expected change in the measured variable can tell us if the countermeasure was effective or not, but not how effective it was. Conflict studies can say more about the changes, but even conflicts are difficult to transform into accident and casualty changes.

If accident data are available, they are normally of little use in this phase, since the time period is too short to reveal any significant changes. It might be advisable, however, to closely follow the reported accidents. This can be an early warning system to show if the situation has become worse than expected.

This could be considered a bit pessimistic, but experience shows that road users can react in a completely different way than engineers or other safety specialists expect them to do. They are human beings and as such adjust to changes. So, therefore, one should be prepared for unexpected and bad things to occur, even though in most cases just good things happen.

8.6 Long-term evaluation

Long-term evaluation takes place during a longer period and comes after the initial monitoring period. The aim is to estimate the effect of the countermeasure.

If there are before studies for speeds etc., such studies could be repeated one, two or three years after the implementation, if they have been repeated as part of the initial follow-up. Accident data, however, is more important in this stage than in the initial monitoring.

8.6.1 Changes in the environment

There are always changes in traffic and traffic environment. The traffic volumes are normally increasing. The composition of the vehicle fleet is changing, cars get stronger engines and more safety equipment. Weather, traffic safety awareness among people, everything changes. All these changes influence the road safety at the sites. All of the changes from before to after cannot be attributed to the applied countermeasures.

8.6.2 Matched pairs

In theory, the best way of taking care of all environmental effects is to have matched pairs in a statistical experiment. This is done by matching possible sites two and two so that the two in every pair are as similar as possible. Then one site in each pair is selected at random and improved and the other one is left unchanged. This theoretically best way is difficult to achieve, since it is often hard to convince road authorities to leave sites with big problems untreated, even if the sites will be untreated for a few years only, and even if this will increase knowledge and be worthwhile in the long run.

8.6.3 Control groups

To use control groups or control sites is a common way to control for all changes in the environment. That is why it is called "control". The general idea behind this is to select sites that are similar to the adjusted sites but where no countermeasures have been applied. The changes in accidents for these sites, from before to after, is said to be due to all the changes that have taken place in the environment. It is then assumed that the improved places, had they not been improved, would have had the same development.

> *Example:* The number of accidents in a control group was 200 in a before period and 180 in an after period. This 10 % decrease is therefore expected also for the improved sites if nothing had been made to them. So any decrease smaller than 10 % for the improved site is in fact not an improvement but a deterioration.
>
> Suppose instead that the number in the control group increased from 200 to 220. If the treated site had the same number of accidents before and after this means a better situation than expected, that is, an improvement.

8.6.4 Deciding sizes of control groups

The use of control groups is necessary for good estimates. It does however increase the variance of estimated effects. Higher numbers give smaller increases in the variance. The control groups should therefore be large enough so that the increase in the variance is not too large. There are different practical rules giving examples of the size. Two such rules could be mentioned:

- The accident numbers for control groups should be at least 10 times the numbers at the changed site.
- The accident numbers for control groups should be at least 200.

The effect and reason behind such practical rules can be seen in the variance formula in the section "To estimate the effect" (see below). The rules are recommendations and not absolute requirements. As important, or maybe even more important, as having a low variance, is to avoid bias. There will be bias if the accident situation in control groups differs from that in the changed sites. So selecting representative control groups is more important then selecting large groups. The size of the variance can be estimated, but bias can in most cases not be estimated.

8.6.5 Test of independence

Chi-square (χ^2) test is a test that is widely used to test independence. This is a test to see if the change in accidents was due to the treatment or if the change could have occurred by chance. The test variable is noted as χ^2.

The test does not say anything about the size of the effect, just if the outcome could be due to randomness or not. It is easy to use and a way to get an initial description.

It can be described by using the notation from Microsoft Excel. Excel includes a function that calculates the probability that the outcome could happen by chance. The function is called CHITEST.

Example: A follow-up has given the following numbers of accidents.

	Improved sites	Control sites	Total
Before	20	200	220
After	16	220	236
Total	36	420	456

The expected numbers have to be calculated first before the CHITEST can be applied. The expected number in each cell is row total multiplied with column total divided by the total number. Thus, the expected number in the first cell is 220*36/456=17.37.

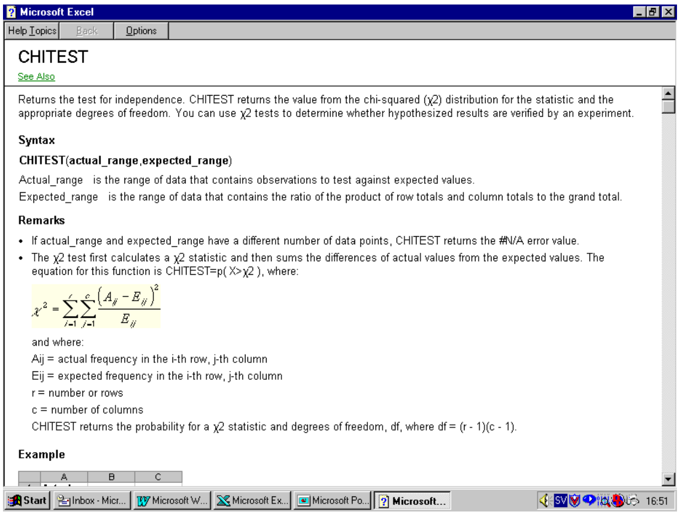
All expected values are shown in the table below.

	Improved sites	Control sites	Total
Before	17.37	202.63	220
After	18.63	217.37	236
Total	36	420	456

These values are used in Microsoft Excel and the function CHITEST tells us that the probability to have an outcome like this or even more extreme is 66 %. This is much more than the 5 % needed in order to say that the countermeasure was successful. So there is no significant change due to the countermeasure.

It is easy to use Microsoft Excel for calculations because it gives the probabilities directly. Other calculations give a value that has to be compared with values in a χ^2-table before it is possible to get the probability and say if it is significant or not.

Below is a printout that shows how the function CHITEST works.



Microsoft Excel

Help Topics | Back | Options

CHITEST

See Also

Returns the test for independence. CHITEST returns the value from the chi-squared (χ2) distribution for the statistic and the appropriate degrees of freedom. You can use χ2 tests to determine whether hypothesized results are verified by an experiment.

Syntax

CHITEST(actual_range,expected_range)

Actual_range is the range of data that contains observations to test against expected values.

Expected_range is the range of data that contains the ratio of the product of row totals and column totals to the grand total.

Remarks

- If actual_range and expected_range have a different number of data points, CHITEST returns the #N/A error value.
- The χ2 test first calculates a χ2 statistic and then sums the differences of actual values from the expected values. The equation for this function is CHITEST=p(X>χ2), where:

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{\left(A_{ij}-E_{ij}\right)^2}{E_{ij}}$$

and where:

Aij = actual frequency in the i-th row, j-th column

Eij = expected frequency in the i-th row, j-th column

r = number or rows

c = number of columns

CHITEST returns the probability for a χ2 statistic and degrees of freedom, df, where df = (r - 1)(c - 1).

Example

8.7 To estimate the effect

When the previous test gives significant results, it is interesting to estimate the effect. Even if there is not a significant result, it is interesting to estimate the effect and to get confidence intervals for that effect.

The statistical calculations will not be shown here since this is not within the scope of this paper. The notation has also been simplified to gain easier understanding. The theory can be found in different statistical textbooks, but the best references may be the works by Ezra Hauer.

The formula for estimation is shown below. K, L, M and N are the number of accidents.

	Improved sites	**Control sites**
Before	K	M
After	L	N

The critical assumption behind this method is that the changes in the improved sites, had they not been improved, would have been the same as the changes in control sites. This assumption makes it necessary to be very careful when selecting the control sites, so that they are as similar as possible to the improved sites.

We would expect K*(N/M) accidents to happen in the after period at the improved sites, if they had not been improved, or if the countermeasure had no effect. But they were improved and the actual outcome is L. Thus L/(K*(N/M)) is an index of effectiveness. Let us call this θ. Then 1-θ is the actual effect.

Consider the same example as before:

	Improved sites	Control sites
Before	20	200
After	16	220

The expected number of accidents during the after period is:

$$20 * \frac{220}{200} = 22$$

This can be compared with the actual number 16. The effect is estimated to be:

1-16/22 = 27 %, that is, a 27 % decrease in accidents.

Variance of the estimate θ is approximately estimated by:
$\text{var}\ \theta \approx (LM/KN)^2\ (1/L+1/K+1/M+1/N)$

$(1-\theta) \pm 1.96 * \text{var}\sqrt{(1-\theta)}$ gives the endpoints of a 95 % confidence interval for the effect. Since the variance for (1-θ) is exactly the same as the variance for θ the endpoints are:

0.272727 ± 0.497983

A 95 % confidence interval for the effect is between -0.22526 and 0.77071. Minus means an increase in accidents and plus a decrease. Since the interval covers zero, the conclusion is that this outcome could have occurred by chance.

The result is that the point estimate of the effect is 0.27 (27 %) and that a 95 % confidence interval is between -0.23 and 0.77.

8.8 Short-term versus long-term effects

It is not uncommon that the initial effects are not so good as the long-term effects. One reason for this is that the road users can initially be unfamiliar with the new road site and its design. This could lead to accidents. When the road users get used to the new site, fewer accidents can happen. To avoid complicating the long-term effect estimations, the first time after the opening should be treated separately in the after period follow-up.

8.9 Regression-to-the-mean

Accidents occur at random. For example, if there are 100 sites, there are always some sites that have high numbers of accidents. The reason could be that the sites are dangerous. But there could also be high numbers because the random fluctuations were unfavorable at those sites. Then the number of accidents will decrease the next year even if nothing is made at these sites. The number of accidents tends to come closer to the mean. This is why this effect is called regression-to-the-mean.

Sites selected for countermeasures normally have high accident numbers. So when the sites are improved, the effect will be overestimated during the follow-up. There are, however, ways to correct for this. One simple method is to exclude the year with the highest number of accident in the before period when estimating the effect. So the number of accidents in the before period is estimated to be fewer than they in fact were.

8.10 Accident migration

Accident migration means that accidents are "transferred" to other places, normally road sections adjacent to the improved site. On these sections the accidents could increase and this would mean that the total effect of the countermeasure is decreased.

> *Example:* A straight road section is followed by three rather sharp curves. Many single accidents happen in one of the curves, the first curve for vehicles coming from one direction. Drivers have not adjusted the speed enough after a long straight road section. This curve is improved but not the other two. Then accidents could migrate to the next curve, which is now the first sharp curve, etc.

Accident migration could also occur if drivers adapt to new behavior at improved sites and continue with this behavior onto old sites.

> *Example*: Speeds are often higher on new road sections. The drivers continue to have a high speed when passing onto old (unimproved) road sections, a speed that is higher than it was before. This would lead to more accidents on the unchanged road.

One way to control if migration effects are present is to follow-up the accident situation on adjacent sites at the same time as on improved sites.

Adjacent sites shall not be included in the control group as this could lead to an overestimation of the effect.

8.11 Strange results

Follow-ups sometimes show many strange results with accidents increasing after an improvement. When this happens, it is a strong warning signal to the engineers that something is wrong, even if it is mentally difficult to accept that the new spot or section is unsafe. But drivers and other road users are perhaps not behaving in the way road safety experts supposed they would.

8.11.1 Higher speeds

Many improvements are nice geometrical solutions that have the disadvantage, from a road safety point of view, that they make it possible to increase speed. Since speed is a very important factor behind severe accidents this is a warning signal. Increased speeds do not necessarily need to increase the number of accidents and casualties but every countermeasure that could increase speed must be examined very closely.

8.11.2 Subjective risk

Road users could also have wrong “information”. He or she could think that certain behavior is safer than is actually the case. This means that the subjective risk is lower than the objective risk.

> *Example:* Research in Sweden has shown that crossing the road at a marked pedestrian crossing, at least in Sweden, could be more dangerous than passing at places where there were no marked pedestrian crossings. The reason is probably that a pedestrian crossing outside a marked crossing is more careful than one passing at the pedestrian crossing.

8.12 Change in under-coverage of accidents

It is commonly known that all accidents are not reported (under-reporting). If the reported percentage is changed, this could of course affect the assessments made.

The existence of a road safety project could change the reporting. When there is more focus on reporting from the police headquarters, reporting is likely to increase.

The use of an additional reporting form makes the procedure more time consuming. This could have the effect that reporting decreases.

However, changes in reporting do not matter for the results if the changes are the same at the improved sites as in the control group. This is an important factor to consider when selecting the control sites.

One situation exists, however, where a change in the reporting could affect the evaluation. If the reporting is increased, it is normally increased more for accidents that have the lowest coverage. That is property damage only accidents. If a countermeasure is expected to reduce severe accidents more than slight and damage only, increased reporting could create problems. One solution would be to separate the result of the follow-up into different severity classes, and to make conclusions based on this separation.

8.13 Before and after periods for accident data

When using control groups it is necessary that these have accident data from the same time periods as the data in the improved groups. But it is not necessary that the before period has the same length as the after period. It is, for instance, possible to have three years before and one year after for a preliminary follow-up. This could later be followed by a three year after period using the same before period.