ROAD SAFETY MEASURES ON RURAL ROADS 
IN A COST-BENEFIT CONTEXT

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ABSTRACT

In the European Union, in the year 2000, some 40,000 people died as a result of road accidents. Since 2004, after the enlargement of the EU this number is likely to increase considerably. As will be discussed in this paper, some 60 percent of the fatalities occur on non-urban roads. If motorway fatalities are added, this percentage reaches an average of 67 percent for 24 motorized countries, mostly from the EU. This seems to indicate that the safety situation of non-urban roads leaves much to be desired and ways to improve road safety on such roads need to be explored.

Infrastructure safety measures are generally cost intensive and ways should therefore be found to find the most cost-effective measures from among the many possible countermeasures. Over the past few years much progress has been made in the field of cost-benefit evaluation of safety measures.

This paper will cover four main issues. First, the rural road safety situation and its trends over the past few decades will be briefly dealt with. Second, a number of the main issues that could contribute significantly to safer rural roads are presented and discussed. Third, the main requirements for a scientific evaluation of countermeasures to improve rural road safety will be discussed and considered in a cost-benefit framework which will also discuss the many issues related to obtain proper inputs to the evaluation.

1. Introduction

In the European Union, in the year 2000, some 40,000 people died as a result of road accidents. Since 2004, after the enlargement of the EU this number is likely to increase considerably. As will be discussed later in this paper, some 60 percent of the fatalities occur on non-urban roads. At the same time, it is well known that in most countries the majority of motorway length occurs on non-urban roads and motorways are generally regarded as one of the safest parts of the road network, with the lowest fatality rates per million vehicle-kilometers traveled. This seems to indicate that the safety situation of non-urban roads leaves much to be desired and ways to improve road safety on such roads need to be explored.

Infrastructure safety measures are generally cost intensive and ways should therefore be found to find the most cost-effective measures from among the many possible countermeasures. Over the past few years much progress has been made in the field of cost-benefit evaluation of safety measures.

This paper will cover three main issues. First, the rural road safety situation and its trend over the years will be briefly dealt with. Second, countermeasures to improve rural road safety will be discussed and third, safety improvements will be considered in a cost-benefit framework which will also discuss the many issues related to obtain proper inputs to the evaluation.
2. Road safety trends on rural roads

In 1999 the OECD published a report on safety strategies for rural roads (OECD, 1999). In that publication it was noted that the number of fatalities on non-urban roads, excluding motorways, expressed as a percentage of all fatalities in a country, had increased from an average of 55 percent in 1970 to 61 percent in 1996. The average was calculated for 21 countries, most of which belong to the EU. Data were provided by the IRTAD data base kept at the German Federal Institute for Road Research (BASt). Figure 1 presents similar data for 24 countries over the period from 1970 till 2003 (also kindly provided by BASt). It can be seen that the initial average was around 60 percent in the 1970's, decreased during the 1980's and early 1990's and increased again to about 60 percent over the last ten years. It can be seen that initially only some 7-9 countries provided the relevant data but over the past ten years data from most of the 24 countries are available. For the year 2003 data are available for only ten countries and the average for those is 62 percent.

To these figures one should add the fatalities that occur on motorways, which are almost all in non-urban areas. The average percentage of fatalities on motorways rose from around 3.5 percent in the 1970's till about 7 percent in the years 2000. These data, of course, vary widely from country to country depending on the length of motorways and the amount of travel. Table 1 presents data on motorway fatalities and on the amount of travel for a small number of countries which have among the highest percentage length of motorway and amount of travel on them. In many of those countries the percentage of fatalities on motorways doubled from the 1970's till 2003. In some countries the amount trebled and even more. This is, of course, the result of massive construction programs in those countries which also increased the percentage of travel on motorways. Highest percentages occur in the Netherlands, Belgium, Germany and Switzerland (over 30 percent). The fact that motorway travel is generally safe can be glanced from the fact that the percentages of fatalities on these roads are lower by a factor of 2-3 compared with the percentage of travel had the risk of travel be the same on all categories of roads.

Data on the fatality risk of travel on three types of roads are presented in Table 2. As stated above, the risk on motorways is generally half to a quarter the risk on rural roads, although there are exceptions like Austria.

Finally, the OECD report also provided data on the types of collisions that occur on rural roads in a small number of countries. These results are presented in Table 3. The highest percentages are single vehicle accidents, head-on collisions and intersection collisions. These are also the types of collisions which are associated with a number of counter-measures to be discussed in the next section.
PERCENTAGE OF FATALITIES ON RURAL ROADS FROM 1970 TO 2003

Figure 1. Average percentage of fatalities on rural roads and motorways in 24 countries.

Table 1. Percentage of fatalities and vehicle-km traveled on motorways in a number of countries.

<table>
<thead>
<tr>
<th>% of total vehicle-km traveled in 2001</th>
<th>Year</th>
<th>% fatalities on motorways</th>
<th>Year</th>
<th>% fatalities on motorways</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>2003</td>
<td>11.6</td>
<td>1970</td>
<td>2.5</td>
<td>Austria</td>
</tr>
<tr>
<td>34</td>
<td>2001</td>
<td>13.0</td>
<td>1975</td>
<td>7.5</td>
<td>Belgium</td>
</tr>
<tr>
<td>21</td>
<td>2002</td>
<td>11.0</td>
<td>1980</td>
<td>1.6</td>
<td>Denmark</td>
</tr>
<tr>
<td>20</td>
<td>2003</td>
<td>7.9</td>
<td>1970</td>
<td>2.1</td>
<td>France</td>
</tr>
<tr>
<td>33</td>
<td>2003</td>
<td>12.3</td>
<td>1980</td>
<td>6.3</td>
<td>Germany</td>
</tr>
<tr>
<td>39*</td>
<td>2003</td>
<td>11.3</td>
<td>1980</td>
<td>5.4</td>
<td>Netherlands</td>
</tr>
<tr>
<td>34</td>
<td>2002</td>
<td>10.6</td>
<td>1970</td>
<td>1.8</td>
<td>Switzerland</td>
</tr>
<tr>
<td>20</td>
<td>2002</td>
<td>6.4</td>
<td>1970</td>
<td>2.4</td>
<td>United Kingdom</td>
</tr>
</tbody>
</table>

* in 2000
Table 2. Fatality risk per vehicle-km traveled on different types of roads by country.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>Rural roads</th>
<th>Urban roads</th>
<th>Motorways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>24.78</td>
<td>27.29</td>
<td>15.52</td>
</tr>
<tr>
<td>Denmark</td>
<td>21.79</td>
<td>12.62</td>
<td>2.52</td>
</tr>
<tr>
<td>Japan (1994)</td>
<td>15.17</td>
<td>18.39</td>
<td>6.25</td>
</tr>
<tr>
<td>Finland</td>
<td>16.58</td>
<td>11.62</td>
<td>4.82</td>
</tr>
<tr>
<td>Germany (West)</td>
<td>21.45</td>
<td>13.07</td>
<td>5.76</td>
</tr>
<tr>
<td>Netherlands</td>
<td>18.22</td>
<td>16.58</td>
<td>3.54</td>
</tr>
<tr>
<td>Republic of Ireland</td>
<td>13.13</td>
<td>27.79</td>
<td>4.83</td>
</tr>
<tr>
<td>Switzerland</td>
<td>20.69</td>
<td>14.06</td>
<td>6.07</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>12.27</td>
<td>10.65</td>
<td>3.85</td>
</tr>
<tr>
<td>United States</td>
<td>18.52</td>
<td>8.20</td>
<td>5.28</td>
</tr>
</tbody>
</table>

*Source: IRTAD.*

Table 3. Percentage of fatalities by road type and country.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision: head-on</td>
<td>20.5</td>
<td>16.4</td>
<td>31.0</td>
<td>26.0</td>
</tr>
<tr>
<td>Collision: rear-end</td>
<td>6.4</td>
<td>2.6</td>
<td>12.7</td>
<td>9</td>
</tr>
<tr>
<td>Collision: intersection/other</td>
<td>18.0</td>
<td>20.9</td>
<td>8.3 (only crossing collisions)</td>
<td>27 (sideswipe or angle)</td>
</tr>
<tr>
<td>Single-vehicle collision</td>
<td>39.5 (including collisions with animals)</td>
<td>50.8</td>
<td>23.4</td>
<td>25.0</td>
</tr>
<tr>
<td>Collision with pedestrian</td>
<td>6.2</td>
<td>5.9</td>
<td>21.6</td>
<td>11</td>
</tr>
<tr>
<td>Collision with animal</td>
<td>(see above)</td>
<td>3.4</td>
<td>0.2</td>
<td>2 (+ other)</td>
</tr>
</tbody>
</table>

*Source: Individual countries listed.*
3. Some major issues that can significantly improve the safety of rural roads

Before going with great detail into the effectiveness of individual counter-measures that can be applied to improve safety on rural roads, this section will discuss a number of interventions and issues that could greatly improve rural road safety.

3.1. Roadside safety and forgiving roads

As was indicated above some 30 percent of fatalities on rural roads are single vehicle accidents. This figure is also similar on motorways. Roads should be designed and built in such a way that a driver who, for some reason, loses control over his vehicle can survive such a situation without major injury. Roadsides should be designed with gentle slopes, with obstacle free recovery zones and in those instances where this is impossible or uneconomical, high quality crash barriers should be provided that can redirect the errant driver. Although this wisdom has been generally available since the early 1970's, in practice, the majority of rural road length in most countries, still contain a large number of "booby traps" of a wide variety. It seems that there is not the will by Highway authorities to address this issue seriously.

3.2 Speeds, speed limits and police enforcement

Speed is a major contributing factor in both the frequency and severity of crashes. This will be demonstrated in more detail in the next section.

Speeds on most rural roads are high and in many cases speed limits are exceeded in very high percentages. It is not uncommon to observe average speeds which are 5-10 km per hour higher than the speed limit, indicating that the majority of drivers, i.e. over fifty percent, are speeding. The correct balance has to be found between a speed limit which is adhered to, which fits the design limitations and which can induce safe driving conditions. This is a very difficult issue and until such times that concepts like ISA (Intelligent Speed Adaptation) become a practicality, this issue has to decided by setting the correct speed limits by the Highway Authorities on the one hand and by police enforcement of those limits, on the other.

At present most countries tackle this issue by applying mostly manual enforcement assisted by a variety of speed measuring devices, such as radar and laser speed guns, cameras and other methods. The amount of offenders apprehended this way is such that no meaningful reduction in average speeds can be achieved. Some countries, most notably the Netherlands, The United Kingdom and more recently France and Belgium are now beginning to tackle this issue with a massive application of automatic speed enforcement. A recent report by the Parliamentary Office of Science and Technology reports on the installation of some 6000 speed camera sites in the UK (POST, 2004). Initial evaluations indicate a reduction of 35 percent of seriously killed and fatalities at the camera sites. The report also refers to the success of speed cameras in France and similar reductions in crashes in Australia, where speed cameras were applied.

3.3. Widespread application of roundabouts

Another major type of serious and fatal accidents is collisions at intersections. Intersection accidents can most effectively be addressed by the widespread conversion of intersections to roundabouts, of course, where the right conditions for such a conversion exist. The UK has always had a tradition for the widespread application of roundabouts but most other countries, after much initial engineering resistance, have only during the past few decades
started to convert intersections to roundabouts on a major scale. The highly beneficial results have been documented in many safety evaluations and are also discussed in the next section. In those conditions where traffic flows are high enough and the road has a major flow function the more radical solution is, of course, to convert the intersection to a grade separated one.

3.4. Road categorization

Some countries, most notably the Netherlands and Sweden have taken a broader view to tackling the safety situation in general and the rural safety situation in particular. Sweden presented the notion of vision zero and the Netherlands the notion of sustainable safety. In both cases the idea is to provide a physical environment where the driver who is involved in an accident will not sustain serious or fatal injuries. On rural roads this is being achieved by adapting the driver speeds to the character and the category of road in such a way that the correct safe driving speed is achieved intuitively (the Netherlands) and by implementing safety measures that prevent serious crashes such as safe roadsides and separation of opposing directions of travel, even on single carriageways, by physical barriers.

3.5. Black spot management and road safety audits

Finally, in this section, two tools that can greatly contribute to a safer rural road environment should be mentioned. Each road network contains a limited number of locations which have a higher than expected number of accidents. These locations are generally termed "black spots" or "hazardous locations". They can be intersections or short sections of roads. Each country should adopt a systematic procedure for the identification and treatment of such locations. Again, as will be discussed in the next section, the systematic treatment of such locations can reduce the serious accidents by some 15 percent.

Another tool that is becoming of more widespread use in some countries is the introduction of safety audits for new road designs. For each new road design an independent team evaluates the design and looks for safety deficiencies that can be relatively easily corrected.

4. Knowledge on road safety measures and data needs for cost-benefit analysis

4.1. Introduction

This section deals with knowledge and data elements, which are required in order to perform an efficiency assessment (CBA/CEA) of a safety-related measure. The material described in this section is taken mostly from a chapter written by the authors for a manual for the conduct of CBA/CEA evaluations of road safety measures. This manual is being prepared as one of the deliverables flowing from the EU project ROSEBUD and should be completed by the end of 2004.

In order to estimate the cost-effectiveness of a road safety measure, basically, two information elements are needed (e.g. Elvik, 1997a):

- an estimate of the effectiveness of the safety measure in terms of the number of accidents (injuries, fatalities) it can be expected to prevent;
- an estimate of the implementation costs of the measure.
The number of accidents the measure is expected to prevent, is a function of the number of accidents affected at the treated site (area, population) and the safety effect of the treatment. The accidents affected by a safety measure present a target accident group. The safety effect of a treatment is defined as the expected reduction in target accidents following the implementation of the treatment. The effect is usually given in the form of a percentage (e.g. Elvik et al, 1997; Ogden, 1996).

If a cost-benefit analysis is applied, then, besides the above components, the monetary values of the measure’s benefits are also required. The monetary values imply, first of all, accident costs and, depending on the range of other effects considered, may also include costs of travel time, vehicle operating costs, costs of air pollution, costs of traffic noise, etc. Besides, in order to make the costs and benefits comparable (as well as for a comparison of different measures), a conversion of the values to a certain time reference is required. Such an action needs a definition of the economic frame, i.e. a number of information elements (length of service life, discount rate, etc), which are common for the performance of economic estimates.

The data and knowledge components of CBA/CEA to be discussed in this section are:

- Safety effects of measures,
- Number of accidents affected by measures,
- Implementation costs of measures.

4.2. Safety effects

The quantification of the effects of measures aimed at reducing accidents represents a critical point for the application of the CBA and CEA techniques to road safety. The major source of knowledge on safety effects is the evaluation studies, which accompanied the treatments in the past.

The most common form of a safety effect is the percentage of accident reduction following the treatment (sometimes, it is also called the accident reduction factor). The quality of the efficiency assessment of a safety measure (i.e. a prediction of the accident reduction to be attained) depends on the quality of the available values of safety effect. The latter depends on a number of factors, such as:

- The availability of values: does there exist data (values of accident reduction factors) relative to the type of measure considered, applied on a certain type of sites?
- Correctness of data: were the effect values estimated properly, i.e. accounting for confounding factors that may have influenced the results measured?
- Variability of the effect: having a range of results for similar treatments, what is the best estimate of the effect to be applied?
- Local versus general effects: how to combine the evaluation results attained under local conditions (in a country, region, authority) with a more general experience on the subject (e.g. safety effects known from international practice)?
- Changeability of the effect: how can we handle a situation where the safety effect is not stable but changes, depending on traffic volumes?

4.2.1. Availability of values

The safety effect of a measure is available if the estimates of both the average value and the confidence interval of the effect are known. The statement is relevant, where both the type of measure and the type of sites for which the estimates are available, correspond to those for which the CBA/CEA is performed.
The main source of evidence on safety effects is the observational before-after studies (Hauer, 1997). However, due to the diverse nature of road safety measures and the limitations of empirical studies, there are also other methods for quantifying safety effects (WP1, 2003). Those, mostly, provide theoretical values of the effects based on known relationships between risk factors and accidents.

With infrastructure measures the effects can generally be quantified by observing reality and applying appropriate statistical methods. The quantitative approach is facilitated by the fact that the effects are geographically localised on the road network. In other cases (e.g. user-related measures or organisation) the link between the measures adopted and the results in terms of a reduction in accidents are less direct, permitting, at times, only qualitative evaluations.

If we take a close look at the literature, we find a huge amount of publications on road safety, which are devoted to the observed effects of safety treatments. However, the degree of this effect is frequently unclear when a specific project is under consideration. Not rarely, in usual practice, an estimate is supplied which is primarily based on intuition, expectations or some professional experience and not on evidence available in the literature.

Searching for the reasons for this situation, one can conclude that the reported studies differ in ways of treatments’ grouping, evaluation methods, sites’ conditions, sizes of accident sets considered, etc. Therefore, there is a need for arranging the findings of various studies on a systematic basis, making them available for application. Such a systematic consideration requires a definition, on the one hand, of typical treatments, and on the other hand, of typical sites (areas, populations) and target accident groups.

For example, in an Israeli study of safety effects of roads infrastructure improvements (Gitelman, Hakkert et al, 2001), this question was addressed and a database was established which classified the treatment categories, on the one hand, and demonstrated the estimates from different literature sources, on the other hand. Using this database, summary values were developed for each treatment category or for a group of categories. In total, some 250 values of safety effects for infrastructure improvements were provided and served as “default” input to CBA (see examples in Table 4). The summary safety effects are subdivided into two sets, for “rural” and “urban” areas, whereas the measures considered are further subdivided into “junction” and “section” treatments, and then into topic subgroups, e.g. “cross-section”, “medians”, “roadside hazards”, “marking and signing”, etc. Such a structure of the database enables the measures to be easily identified, in accordance with the type of site considered.

To systematize the values of safety effects, three ways are possible:
Table 4. Summary Values of Safety Effects Based on International Experience (Examples)

<table>
<thead>
<tr>
<th>Subgroup of treatments</th>
<th>Safety effect - percent change in total injury accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Junction</strong></td>
<td></td>
</tr>
<tr>
<td>Introducing traffic signals* (All)</td>
<td>-20</td>
</tr>
<tr>
<td>Minor realignment (All)</td>
<td>-15</td>
</tr>
<tr>
<td>Improved visibility conditions (All)</td>
<td>-3</td>
</tr>
<tr>
<td>Introducing stop signs* (All)</td>
<td>-30</td>
</tr>
<tr>
<td><strong>Cross-section profile</strong></td>
<td></td>
</tr>
<tr>
<td>Passing lanes for heavy vehicles (R)</td>
<td>-20</td>
</tr>
<tr>
<td>Widening lanes (All)</td>
<td>-25</td>
</tr>
<tr>
<td>Constructing shoulders (R)</td>
<td>-20</td>
</tr>
<tr>
<td>Major realignment (R)</td>
<td>-30</td>
</tr>
<tr>
<td>Upgrading road in densely populated area (U)</td>
<td>-7</td>
</tr>
<tr>
<td><strong>Road-side hazards</strong></td>
<td></td>
</tr>
<tr>
<td>Attenuaters on fixed objects (R)</td>
<td>-69</td>
</tr>
<tr>
<td>Road side safety barriers (R)</td>
<td>-40</td>
</tr>
<tr>
<td>Removing obstacles (R)</td>
<td>-20</td>
</tr>
<tr>
<td><strong>Medians</strong></td>
<td></td>
</tr>
<tr>
<td>Installation of barriers** (R)</td>
<td>-6</td>
</tr>
<tr>
<td>Widening median (R)</td>
<td>-15</td>
</tr>
<tr>
<td>Introducing median (R)</td>
<td>-4</td>
</tr>
<tr>
<td>Introducing median*** (U)</td>
<td>-7</td>
</tr>
<tr>
<td><strong>Marking and signing</strong></td>
<td></td>
</tr>
<tr>
<td>Rumble strip on shoulders (R)</td>
<td>-15</td>
</tr>
<tr>
<td>Raised pavement marking (R)</td>
<td>-15</td>
</tr>
<tr>
<td>General improvement (U)</td>
<td>-25</td>
</tr>
<tr>
<td>Raised marking of dividing line (U)</td>
<td>-10</td>
</tr>
<tr>
<td><strong>Traffic calming (U)</strong></td>
<td></td>
</tr>
<tr>
<td>Road humps</td>
<td>-48</td>
</tr>
<tr>
<td>30 km/h speed limit zone</td>
<td>-27</td>
</tr>
<tr>
<td>Residential yard</td>
<td>-25</td>
</tr>
<tr>
<td><strong>Pedestrians (U)</strong></td>
<td></td>
</tr>
<tr>
<td>Pedestrian fences</td>
<td>-20</td>
</tr>
<tr>
<td>Refuge at pedestrian crossing</td>
<td>-15</td>
</tr>
</tbody>
</table>

1R - rural area, U - urban area, All - both areas

There are separate values for: *different junction conditions, **different barrier types, ***different road types
a) to document the effects based on meta-analysis;

b) to document the effects based on traditional literature surveys;

c) to provide for theoretical effects based on known relationships between risk factors and accidents.

a. The effects based on meta-analysis

The recommended way to summarize the results of studies is by means of a qualitative meta-analysis. The technique provides both the weighted estimate of the mean effect and a confidence interval for the estimate (a 95% confidence interval is common). The meta-analyses of the evaluation studies served as a firm basis for the Norwegian Traffic Safety Handbook (Elvik et al, 1997), which is known today as the most comprehensive and reliable source of international experience on this issue. The illustrations of the technique and the results of the analyses can be found in papers, e.g. Elvik (1995), Elvik (1997), Elvik (2001).

b. The effects based on traditional literature surveys

For safety measures, for which the results of meta-analysis are yet not available, the evidence of safety effects can be attained by a traditional literature survey. Such a survey can also be devoted to results observed in a specific region or at certain groups of sites, which sometimes, enables a more detailed consideration of the effect values and as a result, better fitting of the available knowledge to the cases considered for CBA/CEA. Some examples of reviews of safety effects on road infrastructure improvements are:

Travers Morgan (1992) - a review of more than 200 studies from Australia, US and other countries, with a detailed classification of treatments and accident groups considered. A range of safety effect values was produced for each treatment type;

Ogden (1994), Ogden (1996) - provide a summary of effectiveness of traffic engineering measures as appears in the Australian literature. Another summary of values recommended for application is given in RTA (1995) but this time in the form of series of values associated with different accident types (as defined by the local accident codes).

For safety measures, for which effects are based on traditional literature surveys, judgmental confidence interval (not based on statistical estimation) still should be presented. The interval is based on the range of results obtained in the evaluation studies and is intended to encompass the range of most of the values.

c. Theoretical effects

In the case of measures for which no previous evaluation studies are available, the estimate of the expected safety effect must be hypothetical. This concerns, for example, the effectiveness of speed limiters in cars. Such devices have not yet been introduced on a wide scale. Their actual safety effects are therefore unknown. Predictions of reductions of accident occurrences can be made on the basis of the effects estimated in speed simulation, utilising the mathematical relationships between speed change and change in accident frequency (Carsten and Tate, 2000).

The empirical relationships between travelling speeds and accidents were established in many studies. One of them, which is widely applied in evaluation studies in the UK, was stated by Finch et al (1994). Finch et al summarized the accident changes associated with the changes in actual travel speeds in different countries (Finland, Denmark, Sweden, Germany, Switzerland, USA) and suggested that an increase (decrease) of 1 kph in average speeds is associated with an increase (decrease) of 3% in injury accidents. Such a “rule of thumb” served for example for predictions of safety effects associated with new forms of speed humps.
Even though the estimate of the safety effect is hypothetical, the confidence interval of the values should be provided. It is based on the assumptions made in calculating the expected safety effects.

4.2.2. Correctness of values

Most of the values of safety effects are provided by after-before comparisons. However, not all the results are correct to the same degree. Due to the fact that safety studies are observational (non-experimental), there are confounding factors, which influence the accident occurrences and, therefore, should be accounted for in the estimation of a real safety effect of the treatment. There is a general assumption that the more known confounding factors a study controls for, the better becomes the basis for concluding that observed changes in road safety were caused by the treatment rather than by confounders (Elvik, 1997).

The nature of confounding factors, which should be accounted for in the evaluation of safety effect, is explained by Hauer (1997):

- Accidents have a random behaviour, for which it is possible to assume a given distribution of frequency (e.g. Poisson). This means that, in some periods, the values measured on given points of the network can be greater (or less) than the average values expected for those points. If the measurement leads to choosing those points for the treatments, a selection bias occurs and, in the measurements made after the treatments, an effect of diminution of accidents is registered (regression to the mean), independent of the treatments.

- Accidents occur in a setting, which, unlike a laboratory, is not “controlled”. Therefore, for some types of accidents, some medium-long term trends can be observed, determined by such factors as the improvement of the safety performances, due to various safety features of vehicles or a change in driver habits. If a decreasing accident trend took place in the previous years, the reduction of accidents after the treatment would probably have occurred even without the treatment.

- For the same reason (lack of controlled environment), other external factors can affect the number of accidents registered where a treatment took place; for example, a reduction or an increase in traffic flows might bring about a variation in the number of accidents, independent of the treatment.

Therefore, to properly quantify the effects of a treatment, a simple before/after comparison is not correct. It is necessary to compare the situation with the treatment (“after”) with the situation that would have existed had the treatment not been applied. The latter presents a corrected value of a previously observed (“before”) situation.

The determination of what situation would have occurred without the treatment is a critical passage of the process and is performed in two steps:

1) determination of the correct before value (of accidents);
2) determination of the correct after value (of accidents) without the treatment.

The first point accounts for the selection bias; the second one - for the uncontrolled environment.

The Empirical Bayes method constitutes an effective instrument for the first point. A correction of “before” accident numbers is performed with the help of reference group statistics, for each site in the treatment group. This is done by means of the known formula of the Empirical Bayes method, which mixes the mean of the reference population, with the number of accidents observed at the site considered (Hauer and Persaud, 1987).
The reference group includes elements of the network which are similar to those where the treatment takes place; in the case of infrastructure improvements, the reference sites should be similar to the treatment sites in most engineering characteristics and are left untreated (unchanged) during the “before” periods of all the sites in the treatment group.

For the second point (the corrected value of accidents without the treatment), two basic methods can be used:

1. using a comparison group - relies on the assumption that changes in the number of accidents in the comparison group correctly predict the changes that would have occurred at the treatment sites in the absence of treatment. The comparison group should be large (to strengthen the significance of the findings), demonstrate a similarity with the treatment group (e.g. from an engineering viewpoint - for the infrastructure improvements), and a high similarity with the treatment group, from the viewpoint of accident changes in the past (Maycock and Summersgill, 1995; Hauer, 1997). The evaluation of the treatment effect is performed by means of the Odds-ratio, where for the “before” period the corrected accident numbers (from the first point) are applied (e.g. Elvik, 1997b).

2. the use of multivariate models, which supply the expected number of accidents as a function of a series of physical and traffic parameters and of general accident trends. The technique of generalized linear models (GLMs), with a Poisson or Negative Binomial distribution for the frequency of accidents, is the most widely accepted today for this purpose. Hauer (1997), Maher and Summersgill (1996) describe a methodology for the development of models.

In practice, a correction due to selection bias is not always necessary. For example, a correction is not performed where a large amount of sites is treated and they are selected without consideration of previous accident experience (e.g. Griffith, 1999).

In general, selecting studies with safety effects, it is important to examine the quality of the studies’ design and to rely more on the findings of those, which satisfy the criteria of correct safety evaluation. Elvik (1995), Elvik (1997), Elvik (2001) and other papers provide examples of such examination, accompanied by a demonstration of differences in safety effects estimated by different groups of studies (defined by the level of control for confounding factors).

For example, Elvik (1997) performed a meta-analysis of 36 studies, which considered the effects of black-spot treatments. The studies were carried out in Great Britain, Norway, Denmark, Germany, France, USA, Canada and Australia. It was found that the results of many studies depend very much on the confounding factors the studies have controlled for. Whether or not the studies have controlled for regression-to-the-mean in the number of accidents is particularly significant. Table 5 presents the results of studies that have controlled for regression-to-the-mean and general trends in the number of accidents. The results indicate that the treatment of both black spots and black sections reduces the number of accidents at the treated sites. In studies which have not controlled for regression-to-the-mean, there was a significantly larger decrease in the number of accidents in some cases than is shown in Table 5 (Elvik 1997). However, in accordance with presently accepted methodology for the evaluation of accident changes (Hauer, 1997), the results of these studies cannot be trusted and are therefore not shown.
Table 5. Effects on accidents of black spot treatment. Source: Elvik (1997)

<table>
<thead>
<tr>
<th>Accident severity</th>
<th>Types of accident affected</th>
<th>Best estimate</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury accidents</td>
<td>All accidents at the spot</td>
<td>-14</td>
<td>(-31; +7)</td>
</tr>
<tr>
<td>Property damage</td>
<td>All accidents at the spot</td>
<td>+0</td>
<td>(-27; +38)</td>
</tr>
<tr>
<td>only accidents</td>
<td>All accidents at the spot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1.1 Black section treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury accidents</td>
<td>All accidents on section</td>
<td>-44</td>
<td>(-61; -18)</td>
</tr>
<tr>
<td>Property damage</td>
<td>All accidents on section</td>
<td>-16</td>
<td>(-39; +15)</td>
</tr>
<tr>
<td>only accidents</td>
<td>All accidents on section</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another way for estimation of the safety effect of a treatment is by means of a cross-section analysis. In contrast to before-after comparisons, in this case, the safety level of two groups of sites (e.g. road sections or junctions) is considered for the same time period, whereas the major difference between the sites is seen in a certain engineering characteristic, whose influence on safety performance is estimated. As both groups of sites are similar in most traffic and road characteristics and are exposed to the same general accident trends, if a difference between the accident frequencies were found, it could be attributed to the engineering feature considered. Such an evaluation technique is acceptable when the “before” period does not exist, i.e. the sites were built with a specific feature, the safety effect of which it is required to quantify. For example, this occurs when residential areas were originally built with elements of a 30 km zone and a question on the safety effect of these features was raised (Gitelman, Hakkert, 2003).

However, in general, the cross-section analysis has fewer possibilities to account for confounding factors and, therefore, is less recommended for producing safety effects’ values (Griffith, 1999a). A principle exception is when the comparison is based on safety performance functions.

A safety performance function (SPF) is a multivariate model, which establishes a relationship between accidents and traffic flows and (optionally) other road characteristics of the road sites considered. Accidents are estimated as numbers per time period, per site. The term SPF was introduced in the North-American literature (e.g. Hauer 1997; Persaud et al 1999), however the techniques for establishing such relationships were also developed in Europe, especially in the U.K. (Maher and Summersgill, 1996). Actually, SPFs belong to the family of accident prediction models, which are recommended for application on one of the steps of before-after analysis (see above).

The value of a safety effect associated with a certain infrastructure feature can be attained, comparing the estimates provided by the models for similar traffic and road conditions, but for groups of sites with and without the feature considered.

4.2.3. Variability of effects

As stated previously, the data for forecasting the effects of a treatment are, in many cases, derived from measurements made ex-post on similar treatments. The results obtained for similar treatments frequently present a range of values. It is necessary, therefore, in order to be able to utilise the data in the forecasting phase, to define some average values and the confidence intervals of the estimates.
A commonly used method for this is meta-analysis (e.g. Elvik, 1995; Elvik, 2001). The effects estimated for separate studies are combined by means of the log-odds method (Fleiss, 1981). Each estimate is assigned a statistical weight inversely proportional to the variance of the logarithm of the odds ratio.

The estimate of the effect observed at each separate study is, usually, the odds-ratio of accident numbers observed at treated and comparison sites, in before and after periods.

For those cases, where the safety effect refers not to the accident numbers but to accident rates (e.g. the number of accidents per vehicle-kilometer traveled) or to a conditional probability of accidents (e.g. the probability of a fatal accident, given that an accident has occurred), relevant definitions for the odds-ratios and the statistical weights can be found in Elvik (1995).

4.2.4. Local versus general effects

Considering the results of a safety evaluation study, a major question usually arises as to the possibility to combine new findings with those from previous experience. Such a question is quite common because the estimates attained are sometimes insignificant or significant to a certain extent (for example, with p-value < 0.10) and from the practical viewpoint, there is a need to accept or ignore the findings. One should also remember that to prove a significance of the effect, which ranges in 10-20%, the size of accident set considered should be of several hundreds (e.g. Griffith, 1999), a condition that frequently cannot be provided for consideration of a specific treatment.

Another problem can be in that the local result is somewhat at odds with the values reported in other countries. For example, the local value of a safety effect may be too high or indicate an increase in accidents whereas accident reductions were generally observed in other countries. At the same time, in many countries the authorities prefer local values of safety effects to international ones, pointing out the (assumed or established) peculiarity of local conditions, e.g. driver behaviour, road design, climate, etc.

Therefore, sometimes, there is a need to indicate those of the local findings, which are sufficiently strong to serve as a basis for CBA/CEA of the potential projects. For this purpose, some decision rules can be developed as described below.

To examine the local findings on safety effects of road infrastructure improvements, in the Israeli study (Gitelman, Hakkert et al, 2001) two criteria were introduced:

1. significance of the value estimated for local conditions;
2. consistency of the result with the international experience.

For a subdivision of the findings, using the two above criteria, three groups of values (of safety effects) were defined:

I - Values recommended for application (without reservation). This includes findings, which (a) were found significant (p-value < 0.05) and (b) resembled the international results;

II - Values admissible for application (with some reservations). This comprises values which (a) can be seen as significant to a certain extent (p-value < 0.20) and correspond to the range of values which were found in other countries; or (b) were found highly significant for local conditions (p-value < 0.05) but contradict the international findings;

III - Values not recommended for application yet. This includes values, which do not satisfy the demands of groups I and II. Concerning these types of treatment, a follow-up study should be continued, to provide for larger data sets for evaluation and consequently, obtain more significant results.
Using the above decision rules, some 20 estimates of safety effects were found as applicable to local conditions and were introduced into the database of the evaluation tool for CBA of road infrastructure improvements that was developed (Gitelman, Hakkert et al, 2001).

In another way, the new value of a safety effect can be combined with the previous experience, using the meta-analysis technique.

4.2.5. Changeability of the effect

A safety effect is usually given in the form of an average value, suitable for a range of site conditions. As certain relationships exist between traffic volumes and accident frequencies (Hauer 1997; Persaud et al 1999), it is reasonable to expect that the safety effect to occur at a specific site will depend on changes which are expected to take place in the traffic volumes. Even recognizing that the safety effect might be not stable but changes, depending on traffic volumes, the average values of safety effects are usually applied, at least at the stage of a “mini” CBA/CEA. However, when a major change in road infrastructure takes place, e.g. widening or upgrading of a long road section, a more explicit consideration of changes in traffic volumes with a consequent consideration of safety effect is sometimes required.

For such a consideration, safety performance functions can be of help. As introduced in Section 4.2.2., safety performance functions (SPFs) are multivariate models, which establish relationships between accidents and traffic flows and other road characteristics of the road sites considered, i.e. sections or junctions. The dependent variables of the model can be the number of accidents, with different severity levels. Independent variables can be: traffic flows, length of the road segment, width of the lane, width of the shoulder, typology and width of the median, number of intersections per road section, etc. In any case, the expected accident number is a function of the traffic flows considered.

For example, Persaud et al (1999), calibrated SPFs for typical locations on rural roads in Ontario, Canada. To illustrate, for four-legged signalised intersections (in the years 1988-1993) the SPF has the form:

\[
\text{No. of accidents/year} = 0.0005334 \times (\text{total entering AADT}) \exp (0.8776).
\]

For 4-lane freeway in Canada, the SPF was calibrated as follows:

\[
\text{No. of injury accidents} = (\text{Section length})(0.0000537)(\text{AADT})\exp (1.01786).
\]

Maher and Summersgill (1996) reported on models which were developed by the U.K. Transport Research Laboratory for a range of typical sites such as: 4-arm roundabouts; 3-arm major-minor priority junctions on rural single carriageway roads; 4-arm signalized junctions on urban single carriageway roads; 3-arm major-minor priority junctions on urban single carriageway roads; rural single carriageway links on English trunk roads; rural dual-carriageway links on the trunk roads, etc.

The effect of a treatment can be estimated as the difference between the typical accident numbers expected for one section type (or junction) as opposed to the accident number expected for another type, where these values are estimated for the levels of traffic volumes assigned to “before” and “after” periods, accordingly.

4.3. Number of accidents affected by the measures

The number of accidents affected by a measure multiplied by a value of the safety effect provides for the number of accidents prevented due to the measure. Considering the number of accidents affected, two basic situations are possible.
1) When a safety measure is chosen for a specific accident site (area, population), the implementation unit is known. The number of accidents affected by a measure depends on two factors: the statistics of accidents observed at the site over the last few years and the target accident group of the measure. The target accidents are usually obvious as they are dictated by the nature of safety-related measures.

In most cases, a safety treatment is considered for a site with “bad safety records”, i.e. with a record of accidents that occurred at the site. Due to random fluctuations of accidents, on the one hand, and the phenomenon of “selection bias” (Hauer, 1997), on the other hand, the annual number of accidents in the “before” period should be estimated on a 3-5 year basis (and not on the last-year figures which would attribute the measure higher accident-saving potential than it actually has).

If, due to practical reasons, an improvement is planned for a site with no accident record in the last period, it is still possible to account for safety benefits, using typical safety records for this type of sites or the estimates provided by safety performance functions (see Section 4.2.2).

2) When a safety measure is considered for implementation within a large-scale road safety program, first, a typical “unit” of implementation should be defined and then, the number of target accidents expected to occur per year for a typical unit, should be estimated.

In the case of infrastructure improvements, the appropriate unit will often be one junction or one kilometre of road. In the case of area-wide or more general measures, a unit may be a typical area or a certain category of roads. For police enforcement, it may be a kilometre of road with a certain level of enforcement activity (e.g. the number of man-hours per kilometre of road per year).

For example, an economic model developed for the Israeli safety program was based on estimates of savings in severe accident injuries, which could be attained due to the implementation of the program (Hakkert and Gitelman, 1999). Considering each field of the program’s activity, three stages were passed: 1) definition of target accident groups; 2) evaluation of the expected safety effect of the treatments; 3) definition of the implementation scope, which is attainable during the program. Regarding the third stage, two types of activity were defined: national-type (e.g., “enhancing the use of safety restraints in cars”) where potential injury savings were estimated using average nation-wide indices; and a varying-type, i.e. those activities whose scale and sites of application depended on a marginal cost-benefit analysis. The latter type included the road environment and enforcement measures, where the evaluation concerned:

a) five categories of geographic units, i.e. one-kilometer road sections and junctions in urban and rural areas, accordingly (as potential black-spots), and varying-length rural sections (as candidates for creating forgiving roadside conditions);

b) three variants of treatment, i.e. improvement of road infrastructure only, intensive speed enforcement only or both measures combined. For each geographic unit, the most cost-effective variant was chosen.

To avoid any possible bias caused by regression-to-the mean, estimates of the number of accidents that can be prevented by road related measures should be based on accident rates representing the typical level of safety for various categories of road elements and road types (Elvik, 1997a). Table 6 provide an illustration of typical accident rates for roadway elements for the Netherlands.

Two more factors are essential for the evaluation of accident numbers to be saved:

a) the measure can be already implemented to a certain extent. For example, in some countries the initial level of wearing safety belts in cars is rather high, therefore a public
information campaign on the issue will hardly result in significant changes in accident records. Similarly, the black-spot treatment measure is widely applied in many European countries; there is some initial level of police enforcement, etc. As a result, the actual safety potential of the measure, for local conditions, should be estimated as lower than a basic one.

b) the same accidents can be influenced by several kinds of treatments. A combined effect of these measures will be lower than a direct sum of the initial values (e.g. Elvik, 2001a).

4.4. Implementation costs of measures

The implementation costs are generally estimated on an individual basis for each investment project. As to road investment costs, the average cost rates, to be used in master plans, are measured on a per junction or per kilometre of road basis. Road maintenance costs are measured on a per kilometre of road per year basis.

The typical values of costs are essential for the performance of CBA/CEA, especially at the stage of a preliminary evaluation. However, these values are usually unpublished, which strengthens the uncertainties of the evaluation results.

Research efforts can be undertaken to provide for typical values. For example, developing a tool for evaluation of safety benefits of road related measures, in Israel, the typical costs of road infrastructure improvements were explored (Hakkert, Bonjak et al, 2002). The typical components and typical costs were suggested for: a minor realignment of junction, a roundabout, traffic lights’ installation, lighting installation at junction, sealing shoulders, resurfacing on rural roads, etc. For preliminary estimates’ performance, the following values were recommended: a typical treatment of one kilometer black-spot section costs 100,000 NIS\(^1\), a typical treatment of a black-spot junction – 500,000 NIS.

For the efficiency assessment of safety measures at different levels (national, regional, local) there is a great interest in implementation costs fitted to relevant conditions.

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\(^1\) NIS – New Israeli Shekel; presently, 1 Euro = 5.5 NIS
4.5. Conclusions

Lack of information on safety effects and costs as well as doubts on the validity of the available values present one of the major practical barriers for the performance of the efficiency assessment of safety related measures.

Summing up the available knowledge and data, the following recommendations can be drawn up to promote the application of the efficiency assessment for road safety measures:

1. In different countries, many evaluation studies have been conducted which demonstrated the effects of safety related measures on accidents. In order to make them available for CBA/CEA applications, there is a need to arrange them on a systematic basis, i.e. relevant data should be retrieved, ordered, screened and made accessible for CBA/CEA experts.

2. In some countries, such work on systematization of the results of evaluation studies has been performed, i.e. there are databases of values, which are immediately available for application. One of them, which is known today as the most comprehensive source of values of safety effects, is the Norwegian Traffic Safety Handbook (Elvik et al, 1997). The majority of values in the Handbook present a summary of international experience that makes it a reliable source of general values of safety effects associated with various safety measures.

To provide for the local values of safety effects, a systematization of the results of the evaluation studies, which have been performed under local conditions, is required. In Israel, a database on safety effects of road infrastructure improvements was developed in a recent study by Hakkert, Bonjak et al (2002).
3. To stimulate the application of more uniform and well-based values of safety effects in the EU, it would be useful to establish a database with typical values of the effects, based on international experience. The Norwegian Traffic Safety Handbook, in combination with other available sources, can serve as a basis for such a database. The initial part of the database can focus on infrastructure-related measures, as the majority of both available estimates and the requests for application come from this field.

4. Similar to the Norwegian Traffic Safety Handbook, the values of safety effects should be presented for various groups of accidents, as dictated by severity levels and types of accidents affected.

5. The evaluation studies, results of which are accounted for in producing typical values, should satisfy the criteria of a robust safety evaluation.

6. Each value of a safety effect, which is recommended for application, should be presented in the form of a best estimate (weighted average) and a confidence interval of the effect. It should also be accompanied by a list of the evaluation studies, which supplied the basic estimates of the effects. Such a presentation enables: to perform the efficiency assessment, to measure the level of uncertainty in the efficiency assessment’ results, and to systematically update the available values.

7. Since the applicability of the values depends on the correspondence between the countermeasures and the treatment sites (population), which are presented in the database and considered for the efficiency assessment, special attention in the database should be given to a correct definition of those components.

References


