Evaluating road safety and safety effects using Empirical Bayesian method

Harri Peltola
VTT, Technical Research Centre of Finland
Contact: Harri.Peltola@vtt.fi, mobile: +358 40 506 9064

ABSTRACT

The safety evaluation of a given road is frequently based only on accidents happened during recent years. However, due to random variation and rareness of accidents, accident history provides an unreliable estimate of the expected number of accidents in the future. This is even more true regarding evaluation of fatalities. Consequently, if the current safety situation is inadequately evaluated, one can nothing but fail in evaluating the effects of road safety improvements. Similar problems concern so-called black spots with relatively small number of accidents during few last years.

The most reliable estimate of the current road safety situation on a given road can be received using Empirical Bayesian method. In Finland an evaluation programme entitled TARVA using that method was created in 1993 and it has been in constant use ever since. First, TARVA combines information about accident history with the accident model information to evaluate current safety situation. Secondly, effect coefficients are used to evaluate the safety impacts due to one or several simultaneous improvements. Thirdly, the severity of accidents is taken into consideration to evaluate the effects on fatalities. The evaluations can be done easily on the whole national road network.

1. BACKGROUND

Many countries have set ambitious quantified road safety targets (Elvik 1993). Targets alone can not guarantee enhanced safety but they can enhance implementation of cots-effective safety measures. To be able to build up a realistic and effective safety programme, the measures must be selected using latest scientific knowledge on their effects.

Scientific research has produced lots of good estimates on the effects of safety improving measures (Elvik & Vaa 2004). The effects are usually presented as a percentage change in the number of injury accidents. So it is vital to be able to evaluate reliably what would have happened if the road safety measure had not been implemented. Our experience suggests that the greatest mistakes in evaluating the safety effects of road improvements are done while evaluating the current safety situation.

According to the empirical Bayesian method, the best estimate of safety is obtained by combining two sources of information: the accident record for a given study unit (e.g. road section), and an accident prediction model, showing how various factors affect accident occurrence (Elvik 2008).

In Finland, as in many other countries, the traffic safety objectives are expressed in the number of fatalities; the number of traffic deaths should be halved in ten years. Often the number of fatal accidents is too low for reliable model building, but the number of injury accidents is sufficient for modelling. Hence we use the number of injury accidents together with the average severity of accidents (deaths/injury accidents) to estimate how much some measure contributes to road safety improvements. Severe injuries have not been defined in Finnish accident statistics.

2. COMPARING DIFFERENT KINDS OF ACCIDENT MODELS

2.1 Data for accident models

Finnish accident models are based on the number of police-reported injury accidents that have occurred during the last five years. Sometimes we model the number of a certain type of accidents (e.g. those involving motor vehicles only, unprotected road users, animals). We usually make separate models for junctions and road sections. For road sections, we are interested in the number of accidents per vehicle mileage and for junctions the number of accidents per incoming vehicles.

In Finland accident models can quite easily be done for rural highways. All accident and traffic data, and almost all road data from rural roads have been recorded in our road register. In addition to accident data, we have in our registers the following traffic and road data (some examples):

Accident data:	Traffic data:	Road data:
- time and location	- AADT, cars	- pavement width
- consequences	- AADT, heavy vehicles	- curviness
- accident type	- vehicles entering junction	- hilliness
		- sight distances
		- speed limit
		- urban areas nearby

Due to the lack of above mentioned data on urban networks, we have not developed respective accident models for urban streets, even if need for them is obvious.

The average annual daily traffic (AADT) on Finnish main road is about 4 700 automobiles. The total length of the main roads is 13 300 kilometres. Annually about 1 650 injury accidents occur on these roads and 157 person get killed (average 2005-2007). The accident rate is 7 injury accidents / 100 million automobile kilometres and the death rate is 0.7 deaths/ 100 million automobile kilometres. The accident densities are 12 injury accidents and 1,2 deaths /100 road kilometres/year.

The biggest problems in modelling data are caused by missing flow data for unprotected road users and the lack of adequate information of the land use along the road. Using the number of inhabitants near the road in the models solves part of the latter problem (Peltola 2007).

2.2 Different types of accident models

We have developed accident models by using generalised linear modelling techniques, and the GLIM - software (NAG 1986). Usually the models have been done for homogenous road sections. When making the first models, junctions were not separated from road sections. In later models, this separation has been done.

In the beginning we developed quite complicated accident models. The models fitted very well the data. Still there were problems with the "effects" i.e. parameter values of some variables. Because of complicated internal correlations, the "effects" of some variables differed remarkably from those known from many before and after studies. Many factors correlate with the speed limit; e.g. the number of unprotected road users and the land use along the road. These factors are not routinely coded in our road register, so their effects are reflected in the "effect" of speed limit.

After these difficulties, we attempted to develop some models with preset effects of some important factors (speed limit and the existence of road lighting and pedestrian/ bicycle path).

Among road planners and other users of the accident models, there was uncertainty whether same kinds of problems arising from internal correlations would still exist. Hence we tried to make very simple accident models.

Note: The purpose was to use the models together with the accident history to estimate the expected number of accidents in the future. When we attempt to understand the relationships between traffic and road conditions and the number of accidents, we can use more complicated models. Even then, relationships identified of the models must be separately tested by e.g. before and after studies.

2.3 Model comparisons

Having several kinds of models, we did some comparisons to find out their strengths and weaknesses. We made the following tests:

A how well different models fit with the accident data they were fitted in

B how well different models fit with accident data from a year different from those they were fitted in. Different kinds of time periods were used in the comparisons.

With different models we mean here:

- complicated accident models
- complicated accident models with some preset effects (speed limit ...)
- simple accident models.

When comparing accident models with accident data for a different year from those used in modelling, we also used the accident history alone as a predictor. Examples of different kinds of models are presented in Table 1.

Table 1. Examples of different kinds of models (Motor vehicle accidents on single carriageway main roads outside urban areas, road sections).

"Complicated model":

E= 0.156 * A1 * A2 * A3 * A4 * A5 * A6 * MILEAGE, where
E= expected number of injury accidents per year
MILEAGE= motor vehicle mileage as millions of kilometres/year
A1= 1.000 if speed limit = 50 km/h
A1= 0.619 if speed limit = 60 km/h or 70 km/h
A1= 0.662 if speed limit = 80 km/h
A1= 0.604 if speed limit = 100 km/h
A2= exp (0.00091 * (percentage of lighted road length))
A3= exp (-0.005882 * percentage of road length where 300 meter sight distances) A4= exp (0.0279 * percentage of heavy vehicles)
A5= exp (0.0748 * (busy private road junctions/road km))
A6= 1.127 if paved road, width of pavement under 6.9 meters
A6= 1.046 if paved road, width of pavement at least 6.9 meters
A6= 1 if the road is not paved (gravel road)

"Preset model":

E=0.1315*B1 *B2*B3*B4*B5*B6*MILEAGE, where
B1= 0.780 if speed limit = 50 km/h
B1= 0.850 if speed limit = 60 km/h
B1= 0.993 if speed limit = 70 km/h
B1= 1.000 if speed limit = 80 km/h
B1= 1.250 if speed limit = 100 km/h
B2= 1 - (0.1 * (percentage of lighted road length/100))
B3= exp (-0.009952 * percentage of road length where 300 meter sight distances) B4= exp (0.01485 * percentage of heavy vehicles)
B5= exp (0.1368 * (busy private road junctions/road km)
B6= 1.201 if paved road, width of pavement under 6.9 meters
B6= 1.110 if paved road, width of pavement at least 6.9 meters
B6= 1 if the road is not paved (gravel road)

"Simple model": E= 0.0173 * MILEAGE

NOTE: The "simple model" would not be so simple, if the comparison included more variable surroundings. In the comparison only motor vehicle accidents on single carriageway main roads outside urban areas were included (road sections).

2.4 Results of the comparisons

2.4.1 Fit with the data used in modelling

When developing the complicated accident models, it is obvious that the model prediction fits quite well the accident data they were fitted from. However, it was not so sure that the models with some preset effects would fit very well the actual accident history. So we tested how well the preset models fit with the accident data on roads with different speed limits (the accident data they were fitted from). The two preset effects in the models were the effect of speed limit and the effect of a pedestrian/bicycle lane.

The preset accident models were tested with the data from 10 highways where during five years had occurred 4 600 injury accidents. The number of accidents was predicted by the models separately for every road section, and the prediction was compared to accident history. The results are summarised in Table 2.

Table 2. The error of a preset accident model as a percentage of the accident history. The observed number of accidents (accident history, N) is also shown (Peltola & al. 1994).

Speed limit	Accidents involving			Total
	Motor vehicles only	Unprotected road users	Animals	
< 80 km/h	-24% N=388	+38% N=124	(+75%) N=2	-8%
80 km/h	-2% N=1238	+46% N=294	+111% N=27	+9%
100 km/h	+19% N=1993	+120% N=264	-14% N=259	+25%
Total	+7%	+70%	-1%	+16%

+ = the model predicted too many accidents
- = the model predicted too few accidents

We can see from Table 2 that the preset accident models have serious problems. When presetting some values, you can lose the good correlation between the predicted and observed number of accidents. The total number of motor vehicle and animal accidents was quite well predicted by the model. Nevertheless, there are great differences when looking at different speed limits. The predicted number of accidents involving unprotected road user (pedestrian, bicycle) was systematically higher than the observed. Because of the lack of traffic volumes for unprotected road users, the modelling of these accidents is quite difficult.

It seems that presetting the effect of speed limit and a pedestrian/ bicycle lane causes bias comparing to the accident history. So preset accident models are not good when attempting to estimate the expected number of accidents with the model.

2.4.2 Fit with the data from different years than used in modelling

When having all the important variables available, it is easy to make an accident model that fits the data well. And if the accident model is good, it can even predict the number of accidents in the future quite well. To test this, we compared the accident model done for years 1987-1991 to the number of accident years 1992 and even 1985 - 1986. We did the comparisons only for one accident and road type: motor vehicle accidents on paved rural highways outside junctions.

The models described here were developed for over 5 000 homogenous road sections, the average length of which was 2.7 km. A total of 4 700 injury accidents occurred on the studied network in 1987 - 1991.

The accident predicting models compared were:

- I accident history, the number of accidents unchanged *)
- II accident history, the accident risk unchanged (accident rate)
- III preset accident model (the effects of speed limit, pedestrian/bicycle lane and road lightning preset)
- IV quite a complicated accident model

*) Homogenous road sections were so short that there were many sections with no accidents during the five years. Prediction by history fitted much better when the average risk was used as a predictor instead of zero accidents on those sections. So when having 0 accidents, the average risk was used instead.

The goodness of the predictions was estimated by counting how big proportion of the systematic, non-random variation the model can explain (the degree of explanation). The main results of the comparison are presented in Table 3.

Table 3. The degree of explanation when the predicted numbers of accidents are compared to the observed number of accidents in one year and three years (Peltola & al. 1994).

Prediction model	Degree of explanation	
	1 year data	3 years data
I accident history	27,0%	54,6%
II risk history	42,0%	81,9%
III preset model	42,1%	81,3%
IV complicated model	42,8%	82,2%

All the models predict much better the accident data of three years than just one year. In the number of accidents of one year there is so much random variation that it can not be predicted very well regardless the used prediction model.

The accident history is not a good way of predicting accidents even if you would replace the prediction by the average risk when having no accidents. The number of accidents per road section is so low that there seldom happens accidents on the same sections they happened during the years before.

The average risk is quite a good prediction at least for one homogenous road group and one accident group (automobile accidents on paved rural highways outside junctions).

The prediction does not improve very much when making the models more complicated. Preset and complicated accident models are almost as good in predicting accidents. The model without presetting is slightly better.

To study the importance of different explanatory factors, we can study how much of the accident variation different variables can explain. For instance at junctions, traffic flow variables (functions of incoming flows from major and minor road) explained 52 - 78% of the systematic variation of numbers of accidents. All the other statistically significant variables explained an additional 6 - 9% (Kulmala 1995).

We have had similar results concerning vehicle kilometres in explaining the number of accidents on road sections outside junctions. Hence, in terms of percentage of variation explained, traffic flows and mileage are quite in their own class. Naturally, this must not be understood as meaning that the other factors have only minor impact on accidents but to mainly reflect the large variation in vehicle flows and mileage - this variation really dominates the overall variation in the group of explanatory variables.

2.5 Main conclusion from the comparisons

The number of accidents during one year can not be predicted well. Hence there is no meaning to make conclusions from accident data for one year when trying to identify hazardous road sections.

Motor vehicle mileage explains most of the variation of motor vehicle accidents. Adding more explaining variables does not improve the accident model very much. One important reason for this is that the accident models are done for a homogenous group of road sections.

One can conclude that you can use quite simple accident models when estimating the expected number of accidents on a particular road section. To understand and illustrate the relationships between traffic and road conditions and the expected number of accidents, you probably need more complicated models.

In practice this means that reliable estimates of exposure are necessary for developing good accident models. This is true for motor vehicles, for which we have adequate flow data, but also for unprotected road users and animals, for which we have almost no exposure data at all.

This brings up a question: why use a complicated accident prediction model when a simple one is just as good.

3. Evaluating current safety and safety effects using TARVA

At the beginning of 1990's the Finnish Road Administration and VTT concluded that the estimation of avoided accident due to road improvements should be done in two phases: 1) estimation of the current safety situation on an existing road, combining information from simple accident models and accident history 2) the safety effects of road improvements can be estimated using the current safety situation and safety impact coefficients (or crash reduction factors) based on most reliable research results available around the world (TARVA 2009).

The TARVA-estimation of safety effects of road improvements is a four-phase process (see also Figure 1).

1) For each homogeneous road segment, the most reliable estimate of the accident number is calculated from the number of accidents in the past, vehicle mileage and the average accident rate in corresponding conditions. Information about accident history and accident model are combined in a formula which takes into consideration the model's goodness of fit and the random variation in the number of accidents. The weight of the accident model compared to the weight of the accident history is the bigger, the more there is random variation in the accident count.

2) To make a prediction of the number of accidents without road improvements, the most reliable estimate of the number of accidents is corrected by the growth coefficient of the traffic. Also the effects of fundamental changes in land use on the predicted accident number can be taken into consideration by the coefficient.

3) The effects of the measures on injury accidents are then described in terms of impact coefficients. The impacts coefficients have been obtained from the research results of all the relevant countries taking into consideration the differences between countries in traffic regulation and road user behaviour. An example from impacts coefficients: building a new roundabout reduces accidents involving vulnerable road users by 15%, has no effect on animal accidents and reduces vehicle-only accidents by 50%. The effects of several simultaneous road improvements are evaluated so, that overlapping measures are properly taken into account.

4) Road improvement measures can also affect the severity of the accidents remaining on the road after the improvement. These effects can also be taken into consideration in TARVA by using severity change coefficients. Using the evaluated injury accident reduction percentage and knowledge on the average severity (deaths/100 injury accidents) and its change, TARVA gives an estimate of yearly-avoided fatalities. An example from severity change coefficients: building a new roundabout reduces the severity of accidents including vulnerable road users by 30%, has no effect on the severity of animal accidents and reduces the severity of vehicle-only accidents by 50 %.

The principles of evaluating the safety effects of road improvements presented in Figure 1 and TARVA have been used in Finland since 1994. The calculations are done based on extensive and consistent database including all the public roads in Finland.

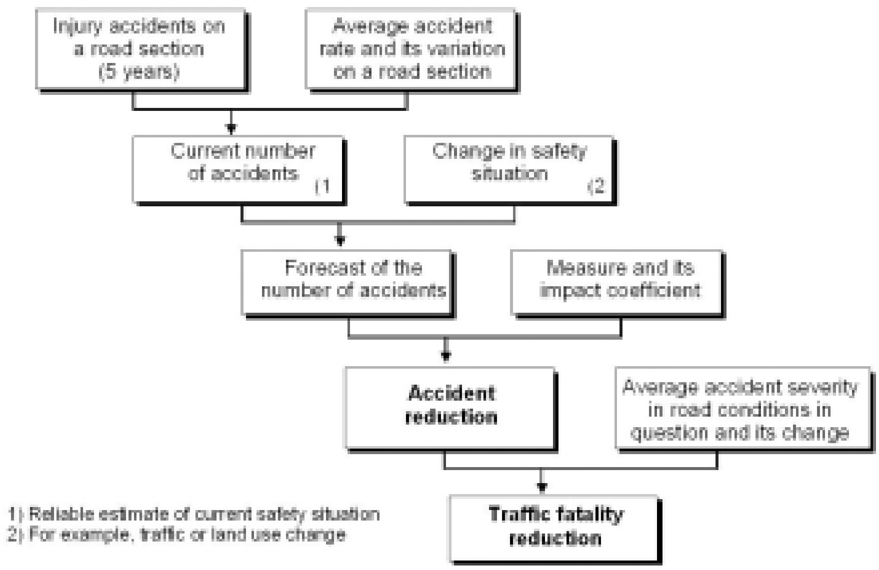

Figure 1. Evaluation of Traffic Safety Effects of Road Improvements (Peltola 1999).

To be able to use relevant information on exposure to accidents, in TARVA we use different models for junctions and road sections. For road sections, the accident prediction model is based on the number of accidents per vehicle mileage and for junctions on the number of accidents per vehicles entering the junction. We calculate three separate types of accidents (those involving motor vehicles only, those involving pedestrians and bicyclists and those involving animals). These are used because road improvements can have very different effects on those accident types. All these different models and types of accidents are handled by the programme, so the user doesn't have to worry about those.

Using the estimates of yearly avoided injury accidents and fatalities caused by road improvements, one can easily calculate also the save in accident costs. When knowing also the costs of the measures, it is easy to calculate which kind of measures are the most effective regarding safety and where those measures pay off most effectively.

The safety effects of road improvements can be evaluated easily and using same data and definitions for all public roads in Finland by using TARVA. The minimum input is i) what is the measure and ii) where it is implemented. There are almost 100 predetermined measures in the programme and own measures can be defined by the user if needed. Also the implementation costs can be entered but the average costs for measures (per km or per measure) are used, if these values are not entered.

The results of the calculations are: the safety situation if no measures are implemented and safety effects of improvements (yearly injury accidents and fatalities). The results show the safety effects in total as well as which measures have caused them. Also economic figures are produced to describe the effectiveness of safety improvements.

As an example of results from the TARVA calculation Table 4 shows which have been the most common measures in reducing injury accidents on Finnish public roads in 2005. Remark: only measures implemented by the road districts are included in the table (not large new road buildings or nationally decided changes in legislation or policies).

Table 4. Yearly avoided injury accidents by the measures implemented in road districts in 2005.

Measure	Reduced injury accidents /year	Proportion (%)
Automatic speed camera enforcement	13,7	38,5
Renovation of road lightning	4,6	12,8
Rumbling road markings	3,1	8,6
New lightning wit breakable poles	2,5	7,0
Building new road side railings	1,8	5,1
More effective crossing markings	1,2	3,4
Improvement of winter maintenance	1,1	2,9
Reflective road side poles	0,9	2,5
Intensified attention to speed limits	0,9	2,5
Speed reducing humps etc.	0,4	1,2
Other measures	4,8	13,6
All measures in total	34,9	100,0

4. CONCLUSIONS

To be able to build up a realistic and effective safety programme, the measures must be selected using latest scientific knowledge on their effects. In addition, evaluations need to be based on best estimates of current safety and take into consideration overlapping measures.

Scientific research has produced lots of good estimates on the effects of safety improving measures. But it is vital to be able to evaluate reliably what would have happened if the road safety measure had not been implemented. The importance of reliable estimates on the safety of different roads is also emphasised by the directive on infrastructure safety.

TARVA, a tool for evaluating safety effects of road improvements uses Empirical Bayesian method to evaluate the current safety situation to make safety effect estimates reliable. This kind of tools can be used to learn more about the accident prone locations as well as the possibilities to enhance traffic safety cost-effectively.

The estimates of cost-effectiveness of evaluated measures help decision makers to choose the measures that should be implemented first.

5. ACKNOWLEDGEMENTS

Accident model studies for rural highways and development of TARVA have been commissioned by the Finnish Road Administration.

6. LITERATURE

Elvik, R. (1993). Quantified road safety targets: A useful tool for policy making? Accident Analysis & Prevention, Volume 25, Pages 569-583.

Elvik, R. (2008). The predictive validity of empirical Bayes estimates of road safety. Accident Analysis & Prevention, Volume 40, Pages 1964-1969.

Elvik, R. & Vaa, T. (2004). The handbook of road safety measures. Oxford: Elsevier Science.

Kulmala, R. (1995) Safety at rural three- and four-arm junctions. Development and application of accident prediction models. VTT Publications 233.

NAG (1986) The GLIM System release 3.77. The Numerical Algorithms Group Limited. 300 p.

Peltola, H. (2006). Accident models. NVF conference in Iceland September 7.-8. 2006. Theme Accident data. Internet: http://ptl.fi/NVFnorden/priv/nvf52/seminarer.htm, cited June 2nd 2009

Peltola, H. (1999) Evaluation of safety effects of road improvements with a new Finnish calculation method, TARVA. World Road Congress, C13/2 Group, Evaluation of Road Safety Measures. PIARC, p. 108 - 118. PIARC 21st World Road Congress. Kuala-Lumpur, Malaysia.

Peltola, H., Kulmala, R. & Kallberg, V-P. (1994) Why use a complicated accident prediction model when a simple one is just as good. 22nd European Transport Forum (The PTRC Summer Annual Meeting). Warwick, England, London, PTRC Education and Research Services Ltd

TARVA (2009) - home pages at web: http://www.tarva.net/tarvaintro.asp