Network safety screening and the identification of hazardous road locations – State-of-the-art and European practice

Summer school SIIV 2012

Catania, September 24-28

Rune Elvik, Institute of Transport Economics

Outline of lecture

- Network safety screening – state-of-the-art
- Current European practice in network safety screening
- Identification of hazardous road locations – state-of-the-art
- Current European practice with respect to the identification of hazardous road locations

Network safety screening

- European directive:
  - *Network safety ranking: A method for identifying, analysing and classifying parts of the existing road network according to their potential for safety development and accident cost savings*
- A general definition:
  - *An analysis of systematic variation in safety across a road network for the purpose of identifying those parts of the network where the expected number of accidents or accident severity is higher than for otherwise similar parts of the road network*

State-of-the-art approach to road network safety screening

- The state-of-the-art approach to road network safety screening is the Safety Analyst method developed in the United States
- The essential elements of this method are described in the Highway Safety Manual (AASHTO 2010)
- Safety Analyst applies the empirical Bayes method for estimating the expected number of accidents
- Safety Analyst applies the peaks-and-profiles algorithm for identifying road sections that have an abnormally high expected number of accidents

Other approaches to network screening

- Accident density methods:
  - *Accident density: Number of accidents per kilometre of road*
  - *In its simplest form, it does not account for traffic volume*
- Accident rate methods:
  - *Accident rate: Number of accidents per million vehicle kilometres*
  - *Assumes a linear relationship between traffic volume and the number of accidents*
- Equivalent property damage (EPDO) methods:
  - *Weighting of accidents according to accident severity*
- Potential safety gain methods:
  - *Compares recorded number of accidents to the safest roads with a comparable or similar road standard (geometry, lanes, etc)*

Comparing approaches to network screening

- Only approaches relying on the empirical Bayes method control for random fluctuations in the number of accidents
- Only approaches relying on the empirical Bayes method account for important factors influencing systematic variation in the number of accidents
- Other approaches are simpler than the empirical Bayes method, but the results are less precise
- Current European practice is in most cases based on the simpler approaches
- Since the use of these should be discouraged, I will not discuss them further

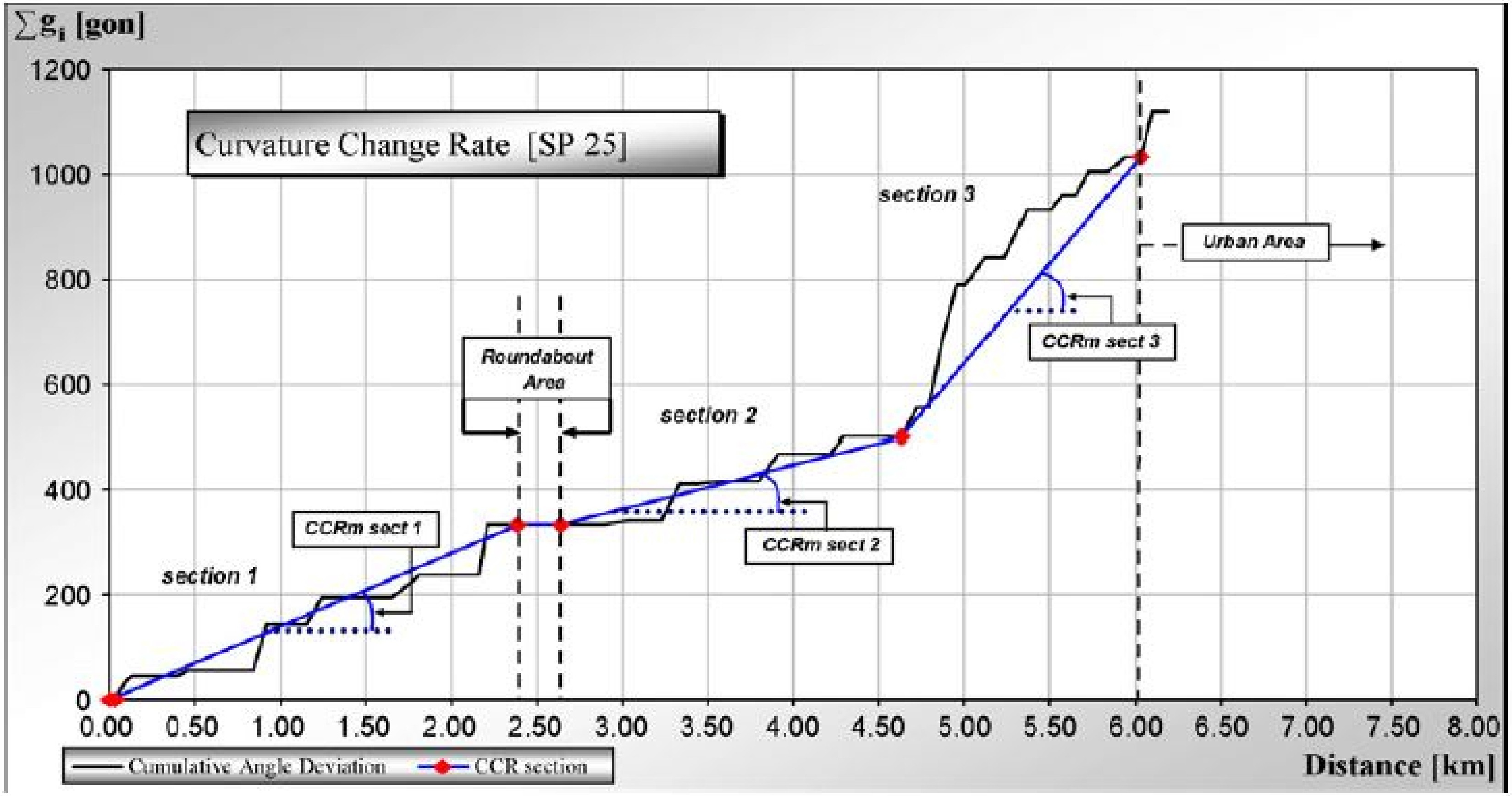
Elements of network screening

- Define relevant road network and elementary unit of analysis
- Determine the treatment of classificatory variables in analysis
- Develop a criterion for safety performance
- Identify road sections with inferior safety performance
- Analyse accidents for road sections with inferior safety performance

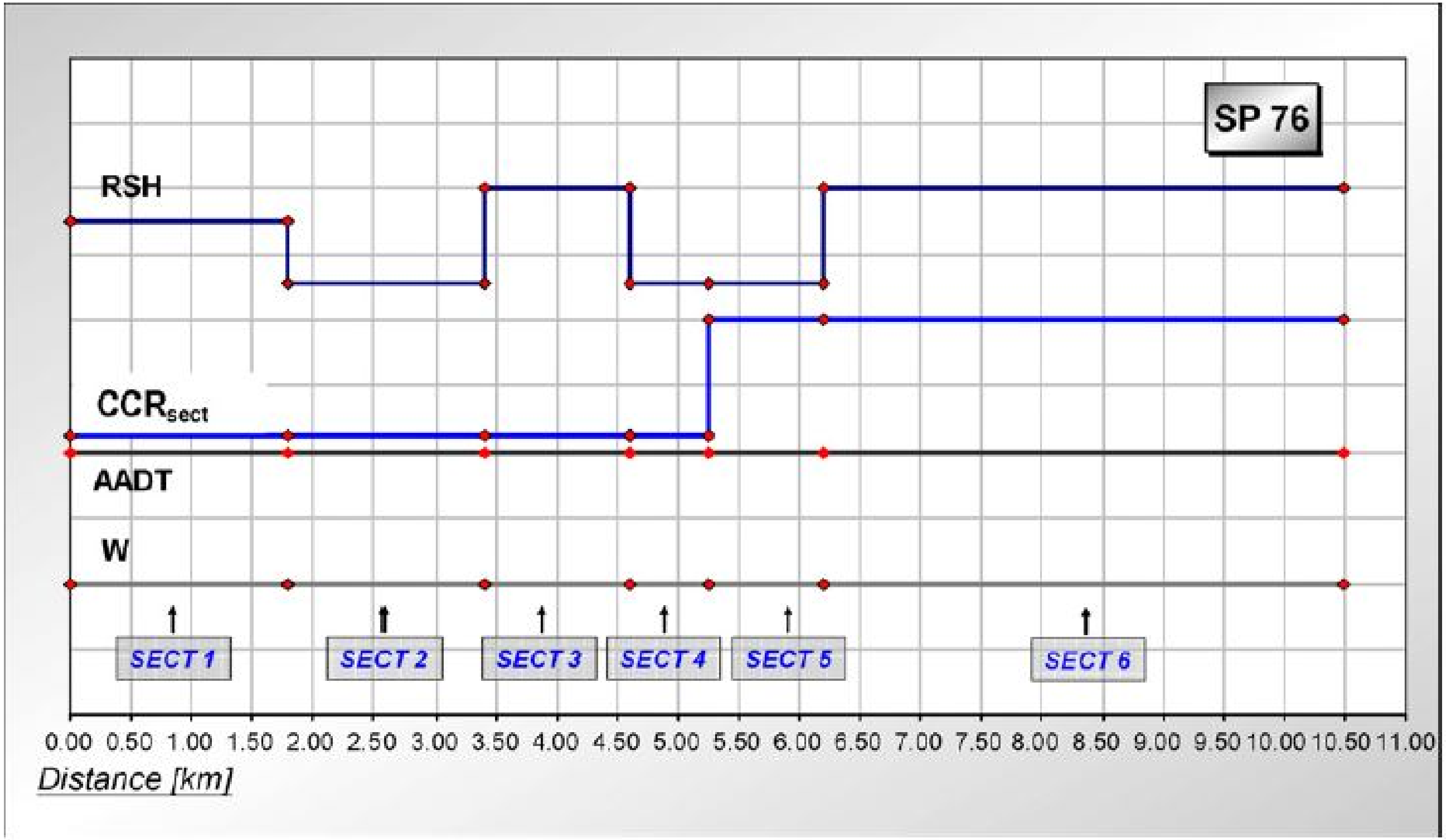
Road network and units of analysis

- Analysis may comprise all roads within a jurisdiction or specific types of roads, such as motorways or roads designated as trunk roads
- The units of analysis (road sections) should ideally speaking be homogeneous with respect to all factors that influence safety (i.e. each section should have a constant traffic volume, constant road width, the same speed limit, etc)
- Homogeneous road sections will often be very short
- Sections as short as 0.1 mile (160 metres) are used in the United States, but a procedure has been developed for aggregating sections

Forming homogeneous sections



Homogeneous sections, continued



The treatment of classificatory variables

- Most countries have formally classified roads
- The question is then whether network screening should be performed separately for each class of road or jointly for all classes of road
- This question is particularly relevant with respect to the development of accident models intended to assess the effects of variables that influence safety
- One option: In Denmark, a fairly detailed classification of roads is applied, and simple models have been developed for each class of road (or type of junction)
- Another option: In Norway, the main categories of roads are identified by coefficients estimated in accident models

Estimation by means of the empirical Bayes method

A weighted mean of the recorded number of accidents and the normal number of accidents for similar sites:

$$E(\lambda_i / R_i) = V_i \cdot E(\lambda_i) + (1 - V_i) \cdot R_i$$

$$V_i = \frac{1}{1 + \dfrac{Var(\lambda_i)}{E(\lambda_i)}}$$

Regression-to-the-mean

Number of sections	Accidents in 1996	Accidents in 1997
20003	0	0.099
1882	1	0.349
344	2	0.834
99	3	1.404
29	4	2.207
10	5	3.500
9	6	4.778
9	7	3.556
8	8	7.375
3	9	8.333
3	10	3.333
3	11	14.000

Regression-to-the-mean (2)

- Abnormally high numbers regress towards the mean (go down) – abnormally low numbers go up
- This can seriously bias the identification of hazardous sites and before-and-after studies of road safety measures
- The empirical Bayes (EB) method can be used to control for regression to the mean

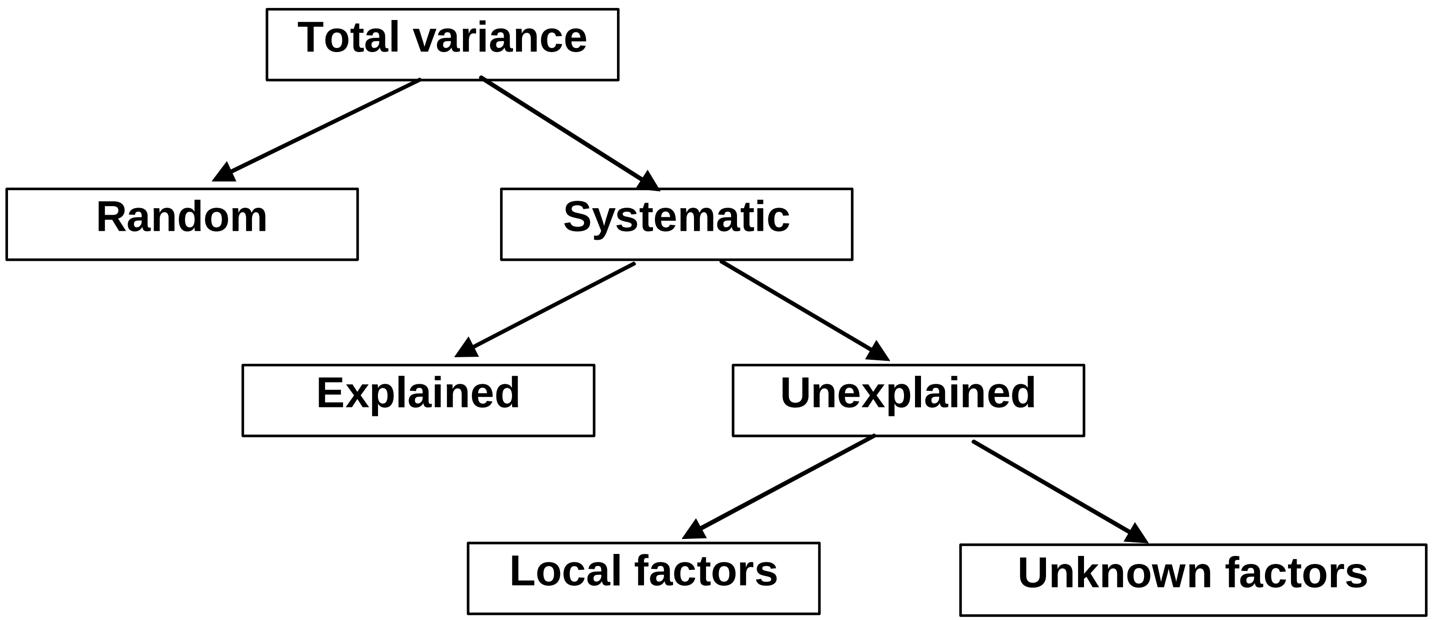
Predicting with the EB-method

Number of sections	Accidents in 1996	Accidents in 1997	Predicted for 1997
20003	0	0.099	0.087
1882	1	0.349	0.499
344	2	0.834	0.910
99	3	1.404	1.322
29	4	2.207	1.733
10	5	3.500	2.145
9	6	4.778	2.556
9	7	3.556	2.968
8	8	7.375	3.379
3	9	8.333	3.791
3	10	3.333	4.202
3	11	14.000	4.614

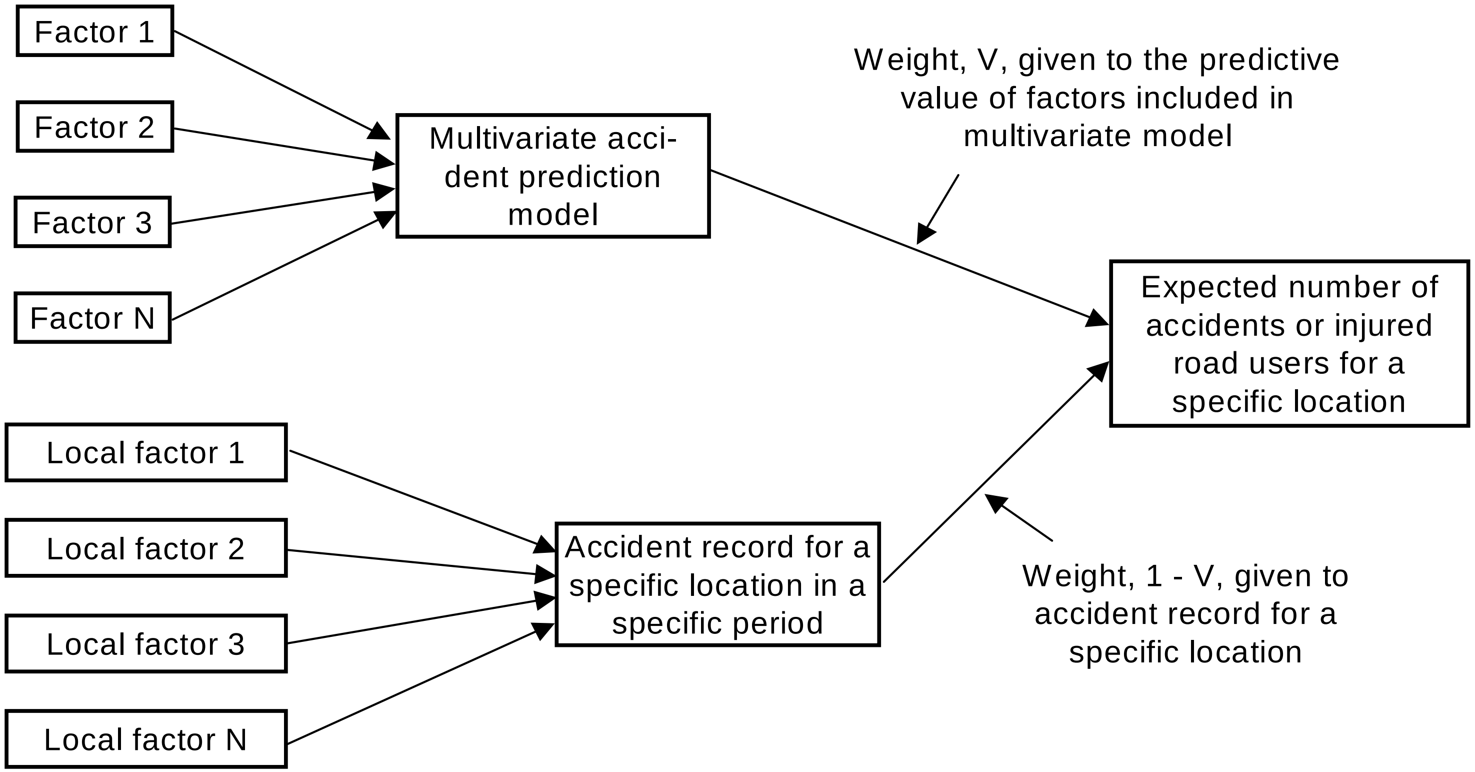
Model coefficients for Norway

Variable	Number of fatalities			Number of critically injured			Number of seriously injured			Number of slightly injured		
	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Constant	-7.154	0.530	0.000	-8.594	0.577	0.000	-6.778	0.301	0.000	-6.281	0.213	0.000
Ln (AADT)	0.842	0.036	0.000	0.829	0.047	0.000	0.809	0.021	0.000	0.972	0.012	0.000
Speed limit 60	-0.020	0.175	0.910	0.052	0.193	0.788	-0.393	0.090	0.000	-0.451	0.055	0.000
Speed limit 70	0.385	0.204	0.059	-0.009	0.244	0.969	-0.338	0.104	0.011	-0.311	0.066	0.000
Speed limit 80	0.172	0.165	0.299	0.161	0.180	0.369	-0.438	0.083	0.000	-0.506	0.049	0.000
Speed limit 90	0.090	0.222	0.686	0.025	0.263	0.923	-0.850	0.135	0.000	-0.743	0.069	0.000
Motorway class B	0.610	0.221	0.006	0.183	0.295	0.537	-0.466	0.148	0.002	-0.987	0.126	0.000
Motorway class A	0.879	0.775	0.256	-0.826	1.268	0.515	-1.155	0.430	0.007	-1.233	0.736	0.094
Ln (number of lanes + 1)	-1.967	0.449	0.000	-1.194	0.520	0.022	-0.523	0.272	0.055	-0.273	0.189	0.148
Ln (junctions/km + 1)	0.082	0.075	0.275	0.170	0.095	0.072	0.124	0.045	0.006	0.232	0.026	0.000
Main road dummy	0.255	0.069	0.000	0.245	0.096	0.011	0.047	0.043	0.270	-0.046	0.024	0.054
Proportion of random variation	0.662			0.808			0.502			0.076		
Proportion of systematic variation explained	0.236			0.132			0.364			0.804		

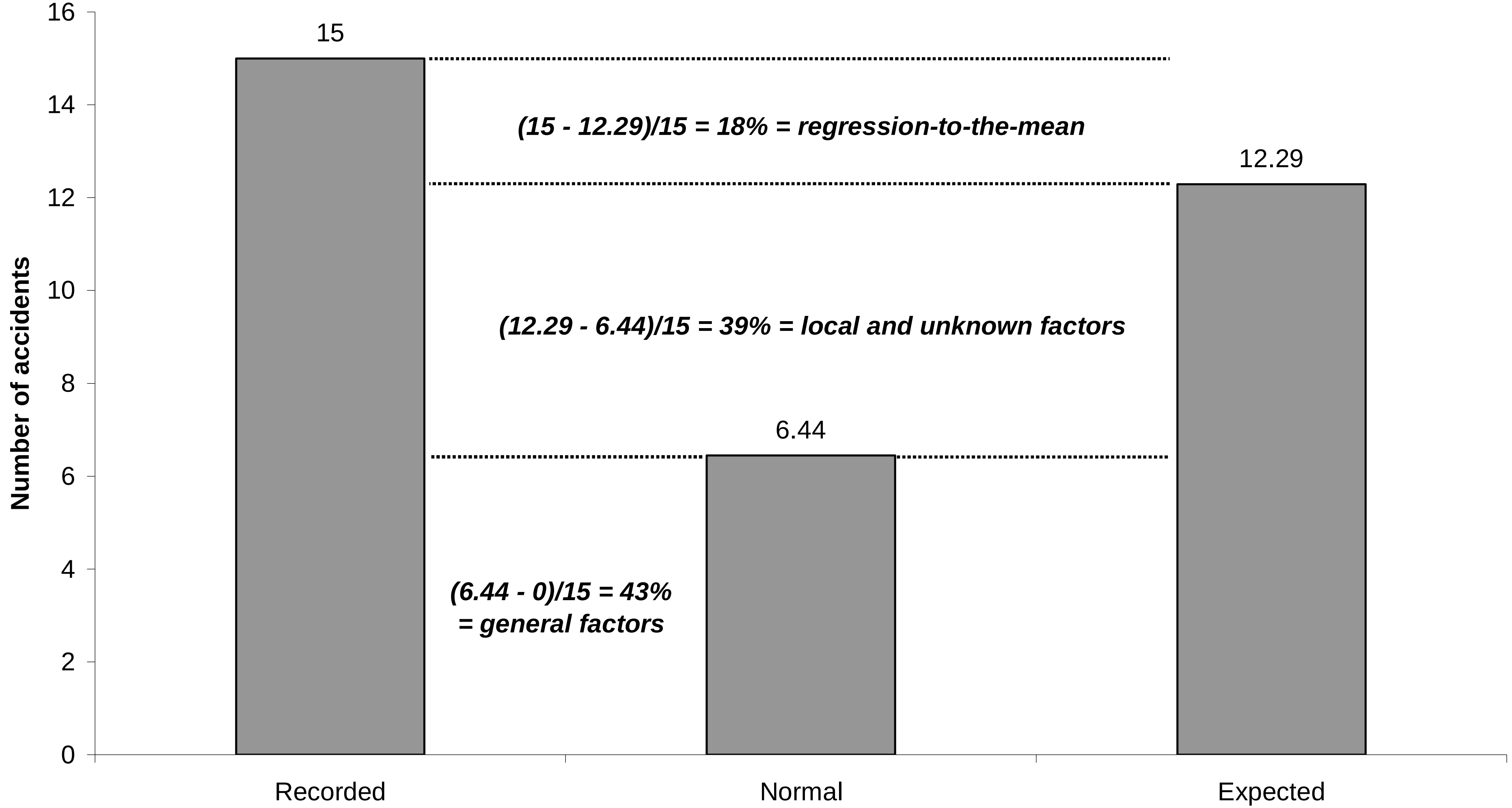
Decomposing variance



Combining accident prediction models and data on local factors



Identifying sources of variation



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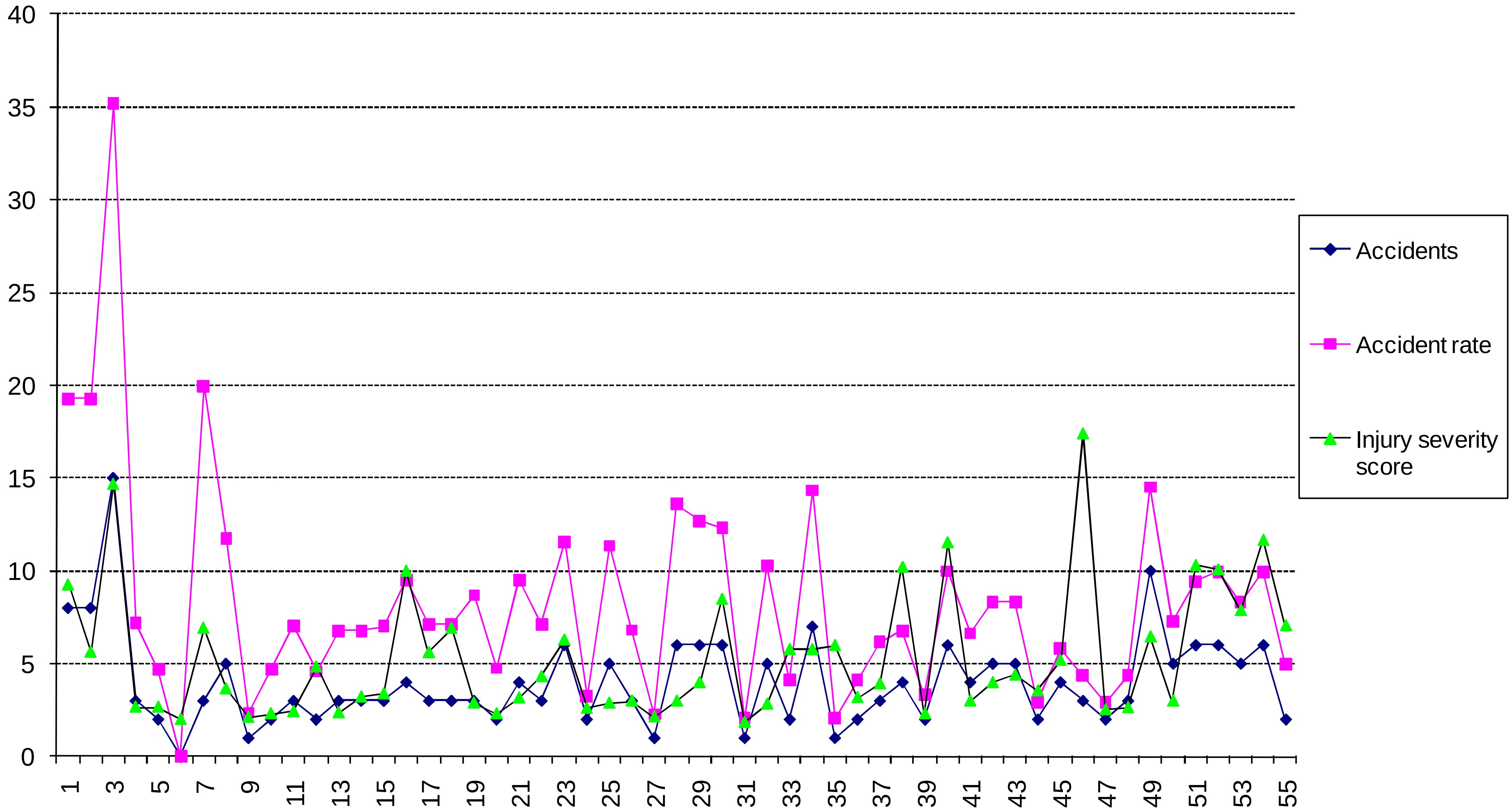
Criteria for safety performance

- Total expected number of accidents (Empirical Bayes estimate)
- Cost-weighted total expected number of accidents
- The excess expected number of accidents compared to a ”normal” level
- Cost-weighted excess number of accidents
- Potential cost-effective accident reduction (i.e. the size of the reduction in accidents that can be attained by means of cost-effective measures)
- An abnormally high proportion of a specific type of accident

Identification of hazardous road sections based on three criteria



Five top sections based on the different criteria

Rank number	Accidents	Accident rate	Injury severity
1	3	3	46
2	49	7	3
3	1	1	54
4	2	2	40
5	34	49	51

Identification of sections with safety problems

- Should be based on an estimate of the expected number of accidents, not the recorded number of accidents
- This is important in order to remove bias caused by random fluctuations (regression-to-the-mean)
- This means that identification of road sections with safety problems should be based on the empirical Bayes method
- The peaks and profiles algorithm of Safety Analyst can be applied to identify longer road sections with safety problems

Peaks and profiles algorithm

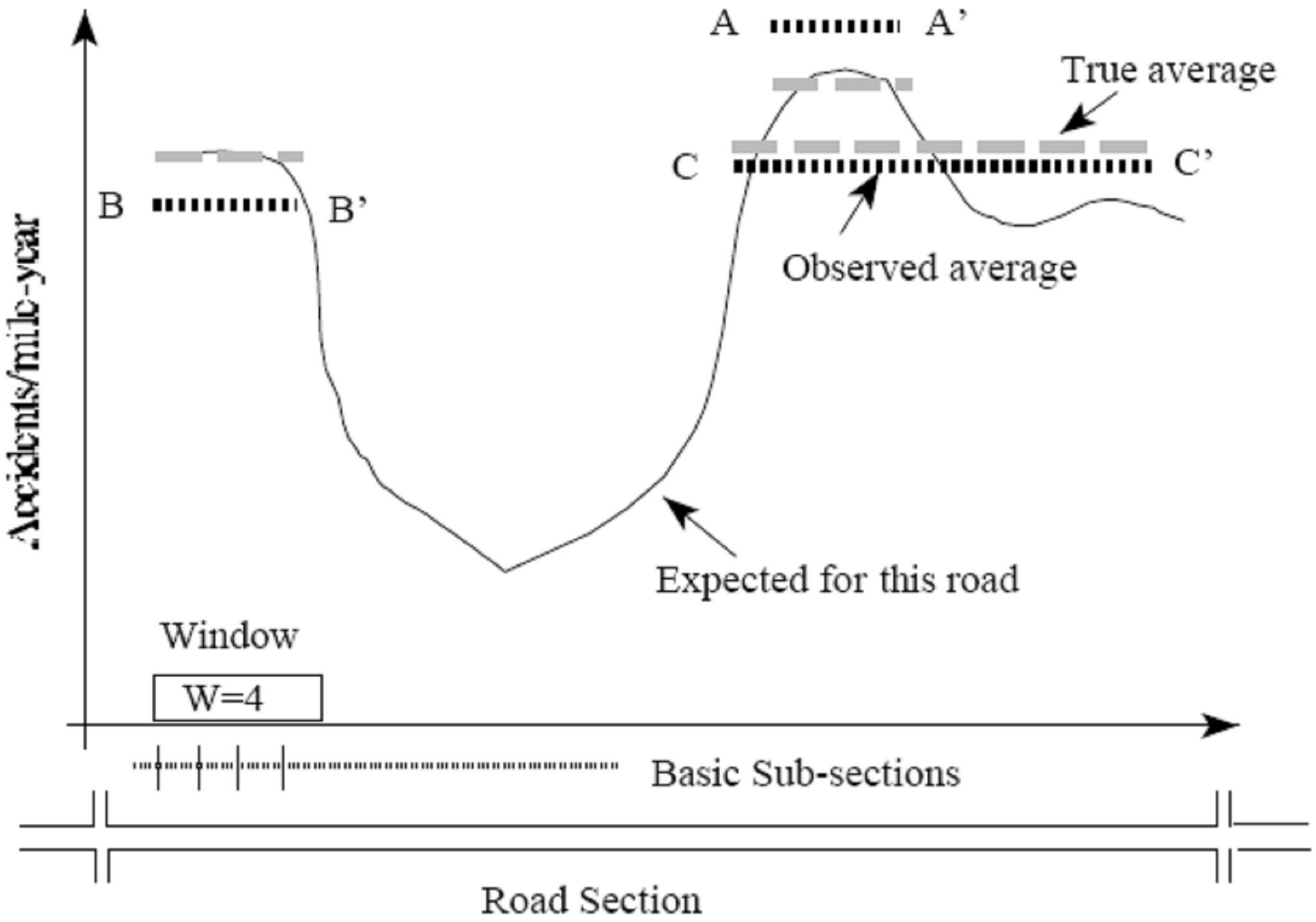


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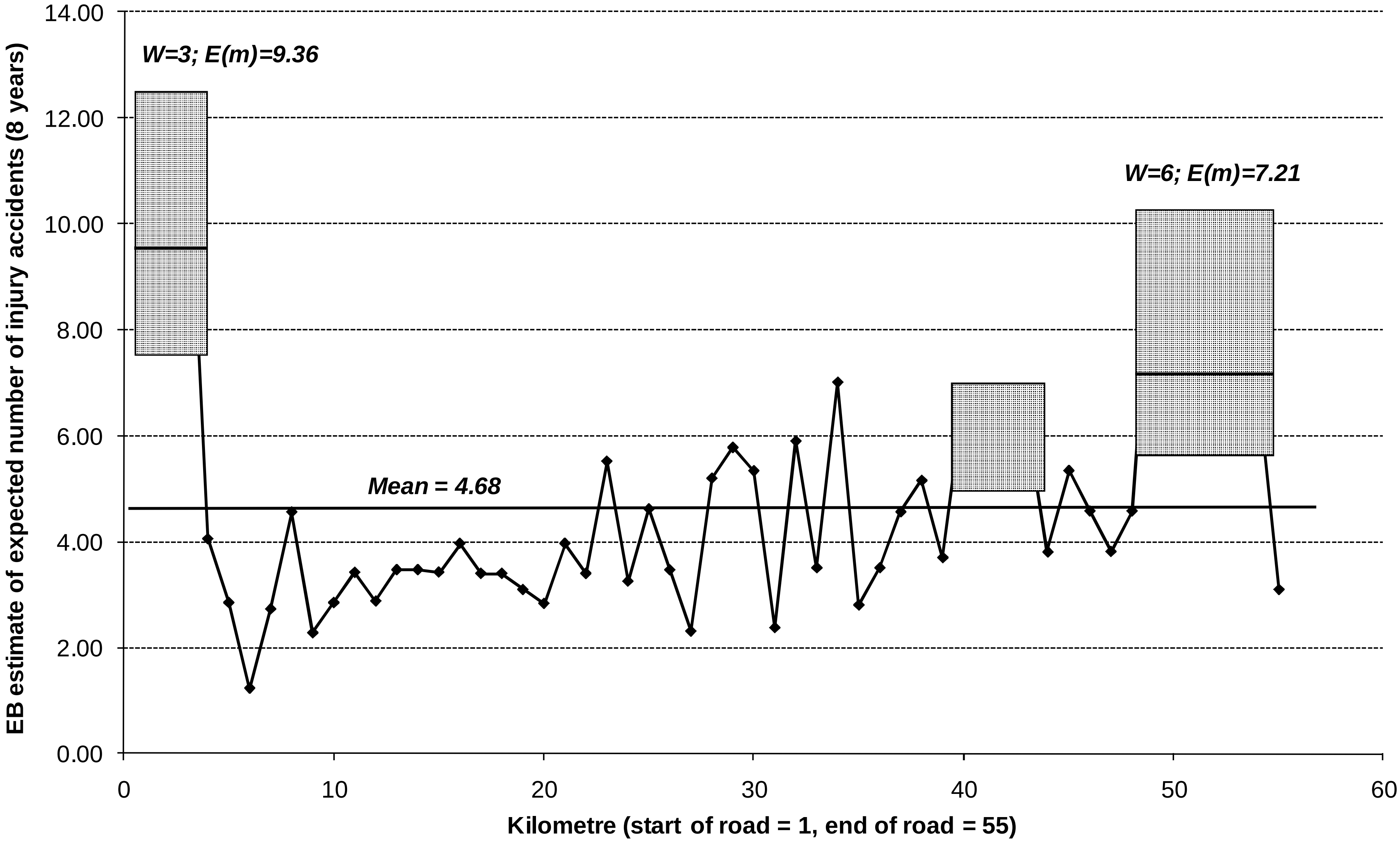
Illustration for Norwegian road



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The basic problem in identifying hazardous road locations

- We want to identify locations whose long-term expected number of accidents is abnormally high
- We cannot observe the long-term expected number of accidents – it has to be estimated
- We can only observe the recorded number of accidents and some of the factors influencing it
- But the recorded number of accidents is not a good estimator of the expected number of accidents

Some hypothetical data

	Groups according to the expected number of accidents					
Count	**0.2**	**0.5**	**1.0**	**3.0**	**4.0**	**Total**
0	532	61	37	5	1	636
1	106	30	37	15	4	193
2	11	8	18	22	7	66
3	1	1	6	22	10	40
4	0	0	2	17	10	29
5			0	10	8	18
6				5	5	10
7				2	3	5
8				2	1	3
9					1	1
Total	650	100	100	100	50	1000

Four categories of sites

- Correct positives:
  - *Expected and recorded number of accidents above critical value*
- False positives:
  - *Recorded number of accidents above critical value, expected number of accidents below*
- Correct negatives:
  - *Expected and recorded number of accidents below critical value*
- False negatives:
  - *Recorded number of accidents below critical value, expected number of accidents above*

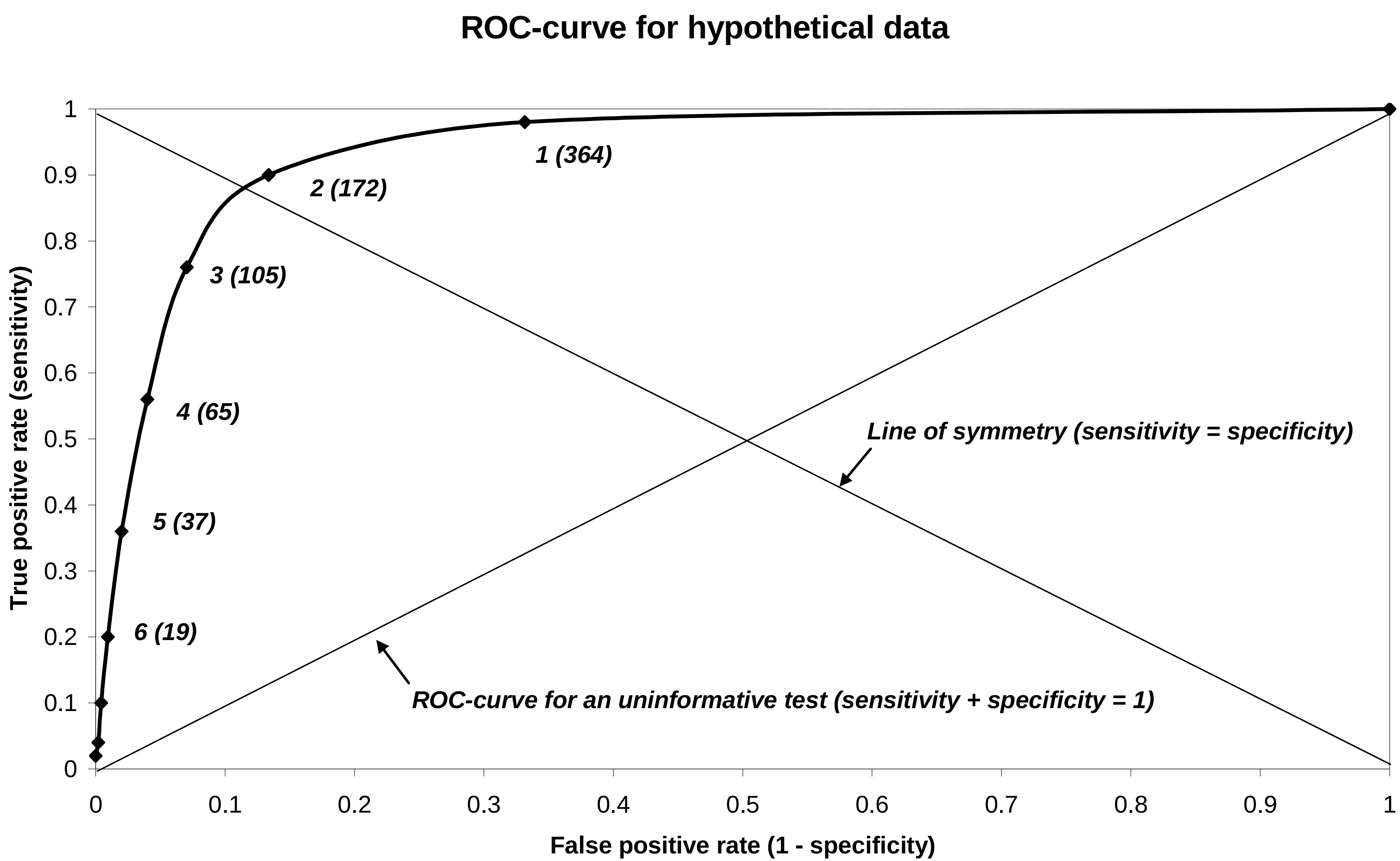
Performance of different criteria of deviance (for a critical expected number of accidents of ≥ 4)

Critical number	Correct negatives	False negatives	Correct positives	False positives	Total sites identified
1	635	1	49	315	364
2	823	5	45	127	172
3	883	12	38	67	105
4	912	22	28	38	66
5	931	32	18	19	37
6	941	40	10	9	19
7	946	45	5	4	9
8	948	48	2	2	4
9	950	49	1	0	1

Epidemiological criteria of diagnostic performance

$$\text{Sensitivity} = \frac{\text{Number of correct positives}}{\text{Total number of positives}}$$

$$\text{Specificity} = \frac{\text{Number of correct negatives}}{\text{Total number of negatives}}$$


ROC-curve for hypothetical data
True positive rate (sensitivity)
False positive rate (1 - specificity)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1 (364)
2 (172)
3 (105)
4 (65)
5 (37)
6 (19)
Line of symmetry (sensitivity = specificity)
ROC-curve for an uninformative test (sensitivity + specificity = 1)

An optimal criterion of deviance

- Maximises the sum of sensitivity and specificity (since both are desirable, but there is a tradeoff between them)
- For the hypothetical data, using 2 accidents is optimal
- A total of 172 sites will be identified, of which 45 are correct positives and 127 are false positives
- To reduce the number of false positives, one may, for example use 4 accidents as the criterion
- 66 sites will then be identified, of which 28 correct positives and 38 false positives

A theoretical definition of a hazardous road location

A hazardous road location is any site that

- Has a higher expected number of accidents
- Than other similar sites
- As a result of local risk factors present at the location

- All three elements of the definition are necessary for the concept to make sense

Implications of the theoretical definition

- Hazardous road location should be identified in terms of the expected number of accidents, not the recorded number of accidents
- Comparison of the expected number of accidents at hazardous road locations to the expected number of accidents at similar locations should be possible
- It should be possible to identify sources of variation in the expected number of accidents, in particular the likely contribution of local risk factors

Characteristics of the state-of-the-art

Characteristics of state-of-the-art approach	Brief justification
1. Hazardous road locations should be identified from a population of sites whose members can be enumerated	This allows theoretical probability distributions for accidents to be fitted to the empirical distribution and allows precise statistical criteria of deviancy to be formulated
2. Hazardous road locations should not be identified by applying a sliding window approach	Use of a sliding window approach has been found (Elvik, 2007; Hauer and Quaye, 1990; Hauer et al., 1993) to greatly inflate the number of false positives
3. Hazardous road locations should be identified in terms of the site-specific expected number of accidents. The empirical Bayes (EB) method should be used to obtain estimates of the expected number of accidents for each site	Research (Persaud et al., 1999; Cheng and Washington, 2005) has found that the empirical Bayes method identifies hazardous road locations more accurately than other techniques. Moreover, it controls for regression-to-the-mean and provides unbiased estimates of the expected number of accidents for each site
4. Hazardous road locations should belong to the upper percentiles of a distribution of site-specific EB-estimates of the expected number of accidents	Research (Elvik, in press) has found that hazardous road locations are most reliably identified in terms of the site-specific EB-estimate of the expected number of accidents. This identifies hazardous locations more accurately than using the excess number of accidents above a normal level as the criterion
5. A suitable period of data for developing an accident prediction model and identifying hazardous road locations is 3–5 years	Research (Cheng and Washington, 2005) has found that use of longer periods adds little to the precision with which hazardous road locations can be identified
6. Accident severity can be considered when identifying hazardous road locations, provided estimates of the site-specific expected number of accidents by severity can be obtained. The recorded distribution of accidents by severity should not be used	Using the recorded number of accidents by severity will introduce major uncertainty due to random fluctuations, in particular for fatal and serious injury accidents which occur more rarely than less serious accidents
7. Specific types of accidents can be considered when identifying hazardous road locations, provided estimates of the site-specific expected number of accidents of each type can be obtained	Again, relying on the recorded number of accidents allows randomness to go uncontrolled, possibly leading to erroneous conclusions. Besides, the shape of the relationship between traffic volume and the number of accidents is likely to vary between different types of accident

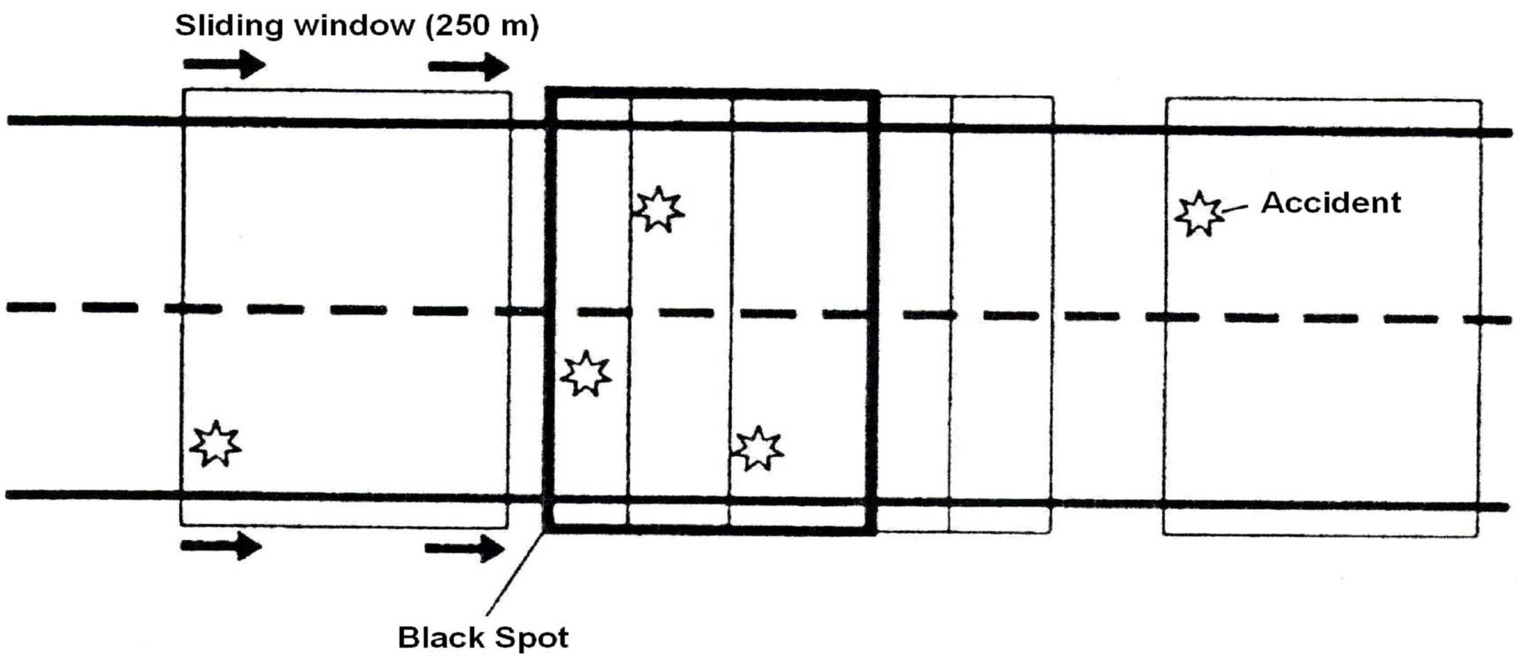
Choices to be made in developing operational definitions of hazardous road locations

- Defining populations of elements or not
- Identifying hazardous road locations by a sliding window
- Reference to the normal level of safety or not
- Length of period used to identify hazardous road locations
- Criterion of deviancy
- Inclusion of accident severity or not

Populations of roadway elements

- It is adviced to define a set of populations of roadway elements, all members of which can be enumerated
- Examples of such populations are:
  - *Sections of a given length*
  - *Intersections (can be further divided into subpopulations)*
  - *Curves with radius within a certain range*
  - *Bridges*
  - *Tunnels*
- Identifying hazardous road locations can be modelled as sampling from a known population, allowing precise statistical criteria of deviancy to be formulated and providing a basis for controlling for regression-to-the-mean

Use of a sliding window is common



Sliding windows inflate the number of false positives

	First	Second	Third
Total identified	113	36	15
Correct positives	42	7	1
False positives	71	29	14
False negatives	8	1	0
True number of positives	50	50	50
Of which identified	42	49	50

Definitions of hazardous road locations in some European countries

Country	Reference to population of sites	Sliding window applied	Reference to normal level of safety	Recorded or expected number of accidents	Accident severity considered	Length of identification period
Austria	No	Yes, 250 m	Yes, by means of critical values for accident rate	Recorded, minimum critical value 3—function of traffic volume	No	3 years
Denmark	Yes, detailed categorisation of roadway elements	Yes, for road sections—variable length	Yes, by means of accident prediction models	Recorded, based on statistical test—minimum four accidents	No	5 years
Flanders	No	Yes, 100 m	No	Recorded, weighted by severity	Yes, by means of weights	3 years
Germany	No	No, accident maps inspected	No	Recorded, minimum values 3 or 5	Yes, by different critical values	1 year (all accidents) or 3 years (injury accidents)
Hungary	No	Yes, 100 or 1000 m	No	Recorded, minimum 4	No	3 years
Norway	Not when identifying black spots	Yes, 100 m (spot) or 1000 m (section)	Yes, by means of normal accident rates for roadway elements	Recorded higher than normal by statistical test, minimum values 4 (spots) or 10 (sections)	Yes, by estimating accident costs and potential savings	5 years
Portugal	Yes, for one definition; no for the other	Yes, for one definition; no for the other	Yes, for one definition; no for the other	Recorded in one definition (minimum 5), expected in the other	Yes in one definition (by severity weighting), no in other	1 or 5 years
Switzerland	Yes, open roads and junctions	No, fixed sections of variable length	Yes	Recorded, a set of critical values	Yes, by different critical values	2 years

Comparison of five techniques for identifying hazardous road locations

- Using the recorded number of accidents
- Using the accident rate (irrespective of the recorded number of accidents)
- Using the combination of the recorded number of accidents and the accident rate (above mean)
- Using empirical Bayes estimates of the expected number of accidents
- Using empirical Bayes estimates of the contribution of local risk factors to the expected number of accidents

Performance of identification techniques

Identification criterion	Correct negatives	Correct positives	False negatives	False positives	Sensitivity	Specificity
			Top 1 % of distribution			
Accident count	19272	134	109	108	0.551	0.994
Accident rate	19232	16	188	187	0.078	0.990
Accident rate and count	19340	86	94	103	0.478	0.995
EB-estimate of accidents	19378	130	53	62	0.710	0.997
EB dispersion criterion	19311	62	121	129	0.339	0.993
			Top 2.5 % of distribution			
Accident count	18788	285	262	288	0.521	0.985
Accident rate	18726	53	418	426	0.113	0.978
Accident rate and count	18928	186	236	273	0.441	0.986
EB-estimate of accidents	18981	338	152	152	0.690	0.992
EB dispersion criterion	19070	105	195	253	0.350	0.987
			Top 5 % of distribution			
Accident count	18065	464	526	568	0.469	0.970
Accident rate	17838	144	805	836	0.152	0.955
Accident rate and count	18308	307	474	534	0.393	0.972
EB-estimate of accidents	18429	692	235	267	0.746	0.986
EB dispersion criterion	18989	136	219	279	0.383	0.986

Length of period used to identify hazardous road locations

Count of accidents in first period	1 year + 1 year	2 years + 2 years	3 years + 3 years	4 years + 4 years
0	0.099	0.166	0.172	0.137
1	0.349	0.495	0.443	0.404
2	0.834	0.936	1.053	0.771
3	1.404	1.541	1.616	1.465
4	2.207	2.054	2.455	2.281
5	3.500	3.606	3.327	2.020
6	4.778	4.536	3.448	2.935
7	3.556	5.167	5.750	4.154
8	7.375	5.214	5.750	3.000
9	8.333	5.500	6.667	7.143
10	3.333	7.700	12.333	4.667

Considering accident severity

- Traditionally, hazardous road locations have been identified in terms of the number of accidents, not taking severity into account
- There is now an increasing desire to take accident severity into account
- This can be done in several ways:
  - *Using a shorter period for more severe accidents (to be avoided)*
  - *Applying different critical values at different levels of severity*
  - *Applying fixed weights by severity (often based on accident costs)*
- It is essential that unbiased estimates of the expected number of accidents are available at all levels of accident severity

Criterion of deviancy

- Various approaches are found:
  - *No criterion applied: hazardous road locations are simply those locations where the accident count is X or more*
  - *A statistical criterion: compare recorded to normal number of accidents and test the difference for statistical significance*
  - *A safety potentials criterion: identify hazardous road locations in terms of the contribution of local risk factors to the accidents*
  - *A percentile criterion: hazardous road locations form the upper percentiles of a distribution*
- It is recommended to:
  - *Identify hazardous road locations in terms of the total exprected number of accidents (EB-estimate)*
  - *Apply the upper percentile criterion*

Conclusions about hazardous road locations

- Define a population of roadway elements from which hazardous road locations are to be identified
- Fit a multivariate accident prediction model to data for this population to obtain estimates of the normal number of accidents
- Identify hazardous road locations in terms of the empirical Bayes estimate of the expected number of accidents
- Select the optimal critical value (1 %, 2.5 %, 5 %, or other)

Suggested reading

- Elvik, Rune. A survey of operational definitions of hazardous road locations in some European countries. *Accident Analysis and Prevention*, 2008, 40, 1830-1835
- Elvik, Rune. Comparative analysis of techniques for identifying hazardous road locations. *Transportation Research Record*, 2008 (2083), 72-75
- Elvik, Rune. A new approach to accident analysis for hazardous road locations. *Transportation Research Record*, 2006, (1953), 50-55