Michael Sørensen
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TØI report 919/2007

Institute of Transport Economics
Norwegian Centre for Transport Research

Black Spot Management and Safety Analysis of Road Networks

- Best Practice Guidelines and Implementation Steps

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Summary:
The report summarizes state-of-the-art approaches and best practice guidelines for black spot management and network safety management with regard to classification of roadway elements, identification, accident analysis and evaluation. The report describes how these recommendations should be implemented.It is recommended that hazardous sites are identified by use of model based methods, ideally speaking the empirical Bayes method. To do this, unambiguously located accident, traffic and road data are needed. The analysis should be made as a blinded matched pair comparison where the hazardous site is compared with a safe site. Alternatively the hazardous site should be compared with the normal accident pattern. The evaluation should employ the empirical Bayed before-and-after design, or be made as a before-after-study supplemented with use of correction factors.

Tittel: Utpekning og analyse av ulykkesbelastede steder og sikkerhetsanalyser av vegsystemer - Beste metoder og implementering

Forfatter(e): *Michael Sørensen; Rune Elvik*

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Sammendrag:
Rapporten sammenfatter moderne tilnærmingsmåter og beste metoder for utpekning og analyse av ulykkesbelastede steder, sikkerhetsanalyser av vegsystemer og evaluering av tiltakenes virkninger. Rapporten beskriver også hvordan disse anbefalingene kan implementeres. Det anbefales at ulykkesbelastede steder utpekes ved bruk av modellbaserte metoder, helst den empiriske Bayes metode. For dette formål er det nødvendig å ha entydig stedfestede ulykkes-, trafikk- og vegdata. Analysen bør gjøres som en blind sammenligning mellom ulykkesstedet og et sikkert sted. Alternativt bør stedet sammenlignes med et normalt ulykkesmønster. Evalueringen bør gjøres som en empirisk Bayes før-etter-analyse eller ved bruk av korreksjonsfaktorer.

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Preface

This report summarizes state-of-the-art approaches and best practice guidelines on black spot management (BSM) and safety analysis of road networks (NSM) on the European road network.

The report is the last of three reports that will document work package 6 (Black Spot Management and Safety Analysis of road Networks – Best Practice Guidelines and Implementation Steps) of the RIPCORD-ISEREST project (**R**oad **I**nfrastructure safety **P**rotection – **CO**re-**R**esearch and **D**evelopment for road safety in Europe; **I**ncreasing **S**af**E**ty and **RE**liability of secondary roads for a **S**ustainable surface **T**ransport).

In the first report "State-of-the-art approaches to road accident black spot management and safety analysis of road networks" (Elvik 2007) the approaches to BSM and NSM currently used in different countries as well as the state-of-the-art approaches to BSM and NSM are described and discussed.

Based on the described state-of-the-art approaches best practice guidelines to BSM and NSM are described in the second report "Best practice guidelines on black spot management and safety analysis of road networks" (Sørensen 2007). The overall difference between the state-of-the-art approaches and best practice guidelines is that the state-of-the-art approaches are the best at the moment known approaches from a theoretical point of view, while the best practice guidelines are the best approaches from a more practical point of view given limited data and resources for developing, implementation and use of the method.

This third report summarizes all relevant aspects of the work package and describes how classification of roadway elements, identification of black spots and hazardous road sections, accident analysis and evaluation of the treatment should be made. Furthermore it describes the necessary steps to implement the described tools for BSM and NSM.

This report can be read independently of the two first reports. However, it is only the key elements that are summarized. Thus, see Elvik (2007) for further clarification for the elements in the state-of-the-art approach and Sørensen (2007) for further clarification for the elements in the best practice guidelines. BSM and NSM immediate look alike, but there are some essential differences. Thus, the BSM and NSM are described in two different chapters. In the end of the report you find some key definitions and explanations of concepts relating primarily to accident theory. This is included to avoid misunderstandings due to different understanding and use of different words.

The project has been funded by the European Commission and the Research Council of Norway. Research Engineer Michael Sørensen and Chief Research Officer Rune Elvik have written this report. Rune Elvik has also been project manager. Head of Department Marika Kolbenstvedt has been responsible for quality checking of the final report. Secretary Trude Rømming has prepared the text for printing.

Valuable comments to the drafts of all three reports in work package 6 have been given by the members of the RIPCORD-consortium.

Oslo, December 2007
Institute of Transport Economics

Lasse Fridstrøm
Managing Director

Marika Kolbenstvedt
Head of Department

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Summary:

Black Spot Management and Safety Analysis of Road Networks

- Best Practice Guidelines and Implementation Steps

Background and objective

Black spot management (BSM) has a long tradition in traffic engineering in several countries in the European Union. It is still considered as a very essential part of the site-specific traffic safety work in several countries. In the last 5 to 10 years, more and more countries have supplemented the traditional black spot management with identification and treatment of hazardous road sections named *safety analysis of road networks or network safety management (NSM)*.

However, the current approaches and quality of both BSM and NSM differ very much from country to country and the work can, in general, be characterised by a lack of standardised definitions and methods.

Thus, the objective of this part of the RIPCORD-ISEREST project in EU's Sixth Framework Programme is to describe and develop *state-of-the-art approaches* and *best practice guidelines* for BSM and NSM. State-of-the-art approaches are described in Elvik (2007), while best practice guidelines are described in Sørensen (2007). This report summarizes the findings and describes the necessary steps to implement the guidelines.

State-of-the-art approaches and best practice guidelines

Approaches for BSM and NSM are divided into state-of-the-art approaches and best practice guidelines:

- *State-of-the-art approaches* are defined as the best currently available approaches from a theoretical point of view.
- *Best practice guidelines* are the best approaches from a more practical point of view and can be used when the data and resources for developing, implementing and using a national method are limited.

Obviously state-of-the-art approaches are to prefer, but data and resources are often limited. In this case it is better to have and use some best practice guidelines rather than refrain from doing anything because the demands for doing the state-of-the-art approaches cannot be satisfied.

It is also preferable that the state-of-the-art approaches are used for all stages of BSM and NSM, but that will not always be a possibility. However, it is recommendable that the approaches as minimum are used for one of the stages, because to a certain it extent can compensate for the lack of use in other stages:

- Use of primitive identification methods place additional burdens on the analysis of accidents to sort out falsely identified locations.
- Use of primitive analysis methods place additional burdens on the identification stage to avoid many false positives that maybe will not be sorted out in the analysis stage.

Definition and philosophy

No standard definition exists of either *black spots* or *hazardous road sections*. However, from a theoretical point of view black spots and hazardous road sections should be defined as follows:

- *Black spot:* Any location that has a higher expected number of accidents, than other similar locations, as a result of local risk factors.
- *Hazardous road section:* Any road section that has a higher expected number and severity of accidents, than other similar road sections, as a result of local and section based accident and injury factors.

The philosophy in BSM and NSM is to use the accident history to identify locations with local risk factors that are related to the local detailed road layout. These locations can be treated inexpensively because it is only the detailed road layout and traffic behaviour that have to be changed and not the general road layout. Therefore, you get a lot of value for money used in terms of traffic safety. However there are some differences between BSM and NSM. These differences are summarized in table S.1.

Table S.1. Overall differences between BSM and NSM.

	BSM	NSM
Nature	– Reactive	– Reactive and proactive
Analysis	– Accident based	– Accident based and general knowledge
Measures	– Specific and remedial	– Remedial and preventive
Severity	– Not included in the identification	– Included in the identification
Length	– < 0.5 km	– 2 - 10 km
Frequency	– Every or every second year	– Every second to fourth year

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Stages in BSM and NSM

Both BSM and NSM can be divided into 10 stages. BSM and NSM starts with a systematic collection of data that enable the identification. Once black spots and hazardous road sections have been identified, accidents are analysed in order to find a common pattern of accidents and factors that contribute to accidents. If this analysis is not successful, it will be concluded that the hazardous location is likely to be false and no treatment will then be implemented. If a treatment believed to be effective is found, it should be implemented and its effects evaluated.

This report focuses on classification of roadway elements, identification principles and criteria, accident analysis and evaluation of the treatment. The stage of treatment is not treated in this report.

Classification of roadway elements

Black spots should be identified by reference to a clearly defined population of roadway elements as for example curves, bridges or four-leg junctions, while hazardous road sections should be identified by reference to 2-10 kilometres homogeneous road sections. This makes it possible to estimate the general expected number of accidents by use of an accident model.

Identification principles and criteria

The identification of hazardous locations should rely on a more or less advanced model based method, ideally speaking the empirical Bayes method. The argument for that is that model based methods are the best to make reliable identification of sites with local risk factors related to road design and traffic control, because systematic variation and partially random fluctuation are taken into consideration.

Hazardous locations should be defined:

- In terms of the expected number of accidents and not the registered number of accidents.
- As locations that have a higher expected number of accidents than the normal expected number on similar roadway elements due to specifically local risk factors.
- As locations where the absolute difference between the expected and normal number of accidents (the savings potential) exceed a predefined number
- Or as a certain percentage of the road network with the largest savings potential

Due to more accidents, accident severity should be an integrated part of the identification criterion in the NSM, but not in the BSM. Severity should be integrated by weighting by use of monetary valuations and the average number of injured of a given severity in different severity categories.

Accident analysis – hypotheses and testing

The state-of-the-art approach for accident analysis consists of two stages:

- Detailed examination of accidents to suggest hypotheses regarding risk factors that may have contributed to the accidents.
- Test of the hypotheses by a double blind comparison of each black or hazardous location and a safe location.

According to the best practice guidelines, the analysis stage should as a minimum consist of:

- A general accident analysis
- A collision diagram
- A road inspection
- Relevant traffic and road analyses

In NSM results from the general accident analysis and the collision diagram should be combined into an extended collision diagram.

The general accident analysis, the collision diagram and the extended collision diagram should be compared with the normal pattern of traffic accidents for the given type of location.

Finally, an active and written assessment of whether the presumed hazardous locations are a true hazardous location should be made.

Evaluation of the treatment

Evaluation of the effects of the treatment should employ the empirical Bayes before-and-after design, because it controls for local changes in traffic volume, long term trends in accidents and regression-to-the-mean.

When it is not possible to make an empirical Bayes before-and-after evaluation, the evaluation should be made as a simpler before-after-study controlling for long-term trends in the number of accidents, local changes in traffic volume and regression-to-the-mean by use of correction factors.

Implementation steps – data collecting and modelling

To make the division of the road system into clearly defined populations of roadway elements and homogeneous road sections it is necessary to collect data about accidents, traffic volume, road design and the surrounding environment.

These data have to be unambiguously located on the road network by use of for example stationing along all roads in the road network. In addition, the data have to be immediately interoperable with each other. This is necessary to develop an accident model.

The development of a model could be summarized in the following steps:

1. Decide what the model should be used for and if the model should be used for state-of-the-art or best practice identification
2. Select possible dependent and independent variables
3. Collect data about these variables
4. Choose a method for estimation
5. Make the estimation based on the work in the previous steps
6. Evaluates the models ability to explain and estimate the systematic variation
7. Make an empirical Bayes estimation of the expected number of accidents on each location.

In the identification of hazardous road sections it is recommended that accident severity is included. To integrate severity it is recommended to develop accident models for each severity category. The development of such models follows the same steps as estimation of a model for all accidents. In addition, it is necessary to provide information about mean costs for traffic accidents.

Implementation steps – accident analysis

In the accident analysis a comparison with a safe location or a normal accident pattern should be made. To make this possible it is necessary to:

1. Make an identification of safe locations using the same procedure as for identification of hazardous locations.
2. Match each hazardous location as closely as possible to a similar safe location.
3. Make a supplementary collection of relevant data for analysis of the matched pair.
4. Make a procedure for the analysis securing that the analysts do not know which site is hazardous and which site is safe.

Regarding the comparison with the normal accident pattern, it is necessary to make an estimation of the normal accident pattern and a procedure for matching the hazardous locations to a relevant pattern.

Maintenance and updating

An essential part of the implementation of the recommended methods is to make a procedure that secure that the data and methods continuously are being maintained and updated and that resources for this work are set aside.

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Sammendrag:

Utpekning og analyse av ulykkesbelastede steder og sikkerhetsanalyser av vegsystemer

– Beste metoder og implementering

Bakgrunn og formål

Utpekning, analyse og utbedring av spesielt ulykkesbelastede steder (black spot management, BSM) har lange tradisjoner i veg- og trafikkteknikk i mange EU-land og betraktes stadig som en uunnværlig del av det stedbundne trafikksikkerhetsarbeidet i mange land. I de siste 5-10 år er BSM blitt supplert med *sikkerhetsanalyser av vegsystemer (network safety management, NSM)* i stadig flere land. Eksisterende metoder for BSM og NSM og kvaliteten på disse varierer dog fra land til land og felles definisjoner og metoder mangler.

Formålet med denne delen av RIPCORD-ISEREST prosjektet under EUs 6. rammeprogram har derfor vært å beskrive og utvikle *moderne tilnærmingsmåter (state-of-the-art approaches)* og *beste metoder (best practice guidelines)* for BSM og NSM. Moderne tilnærmingsmåter er beskrevet i Elvik (2007), mens beste metoder er beskrevet i Sørensen (2007). Denne rapporten sammenfatter resultatene og beskriver nødvendige skritt for å kunne implementere de anbefalte metoder.

Moderne tilnærmingsmåter og beste metoder

En kan skille mellom moderne tilnærmingsmåter og beste metoder for utpekning, analyse og utbedring av ulykkessteder:

- *Moderne tilnærmingsmåter* defineres som foreliggende metoder som er best fra et teoretisk synspunkt.
- *Beste metoder* defineres som beste metoder fra et mer pragmatisk synspunkt, som kan brukes når data og ressurser for utvikling, implementering og bruk av en nasjonal metode er begrensede.

Moderne tilnærmingsmåter er selvsagt å foretrekke, men i en situasjon med begrensede data og ressurser er det bedre å bruke beste metoder i stedet for ikke å gjøre noe for å øke trafikksikkerheten. Ideelt sett bør moderne tilnærmingsmåter brukes i alle arbeidets trinn, men det vil ikke alltid være mulig. Det anbefales at moderne tilnærmingsmåter som minimum brukes i ett av trinnene for å kompensere for manglende bruk i de andre trinnene:

- Bruk av primitive identifikasjonsmetoder medfører ekstra krav til ulykkesanalysen til å sortere steder vekk som er blitt feilaktig utpekt som særlig ulykkesbelastet.
- Bruk av primitive analysemetoder medfører ekstra krav til utpekningen for å unngå at en får med mange falskt identifiserte steder som kanskje ikke blir frasortert i en enkel ulykkesanalyse.

Definisjon og filosofi

Der finnes ingen standard definisjon av verken *ulykkespunkter (black spots)* eller *ulykkesbelastede strekninger (hazardous road sections)*. Ut fra et teoretisk synspunkt bør ulykkespunkter og ulykkesbelastede strekninger defineres slik:

- *Ulykkespunkt:* Ethvert sted som har et høyere forventet ulykkestall, enn andre liknende steder, som et resultat av lokale risikofaktorer.
- *Ulykkesbelastede strekning:* Enhver strekning som har et høyere forventet ulykkestall og ulykkesalvorlighet, enn andre liknende vegstrekninger, som et resultat av lokale og strekningsbaserte ulykkes- og skadefaktorer.

Filosofien for både BSM og NSM er å bruke ulykkeshistorien til å identifisere steder med lokale risikofaktorer som er relatert til den lokale utformningen av vegen. Disse stedene kan relativt billig utbedres da det kun er den lokale detaljutformning og trafikantatferd som skal endres og ikke den generelle vegutformning. Det betyr at man normalt får meget trafikksikkerhet for pengene. Der er imidlertid noen forskjeller mellom BSM og NSM. Disse forskjellene er angitt i tabell S.1.

Tabell S.1. Forskjeller mellom BSM og NSM.

	BSM	NSM
Karakter	– Tilbakevirkende (reaktiv)	– Tilbake- og en fremtidsvirkende (reaktiv og proaktiv)
Ulykkesanalyse	– Ulykkesbasert	– Ulykkesbasert og generell kunnskap
Typer tiltak	– Spesifikke	– Spesifikke og generelle standardtiltak
Bruk av skadegrad	– Bør ikke inkluderes	– Bør inkluderes
Lengde	– < 0,5 km	– 2 – 10 km
Hyppighet	– Hvert eller hvert 2. år	– Hvert 2. til hvert 4. år

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Trinn i BSM og NSM

Både BSM og NSM kan oppdeles i 10 trinn. BSM og NSM starter med en systematisk datainnsamling som muliggjør identifikasjonen. Etter at de ulykkesbelastede steder er utpekt skal ulykker analyseres med henblikk på å identifisere ulykkesmønstre og ulykkesfaktorer. Hvis analysen ikke gir klare resultater bør det konkluderes at den ulykkesbelastede lokaliteten sannsynligvis er falsk og ingen tiltak skal da gjennomføres. Hvis mulige tiltak derimot er funnet bør disse gjennomføres og deres effekt evalueres.

Rapporten fokuserer på oppdeling av vegnett, identifikasjonsprinsipper og kriterier for utpekning av farlige steder, ulykkesanalyse og evaluering av utbedringstiltak. Utbedring av farlige steder behandles ikke i denne rapporten.

Oppdeling av vegnett

Ulykkespunkter bør identifiseres i henhold til en klart definert gruppe av vegelementer, som for eksempel kurver, tunneler og kryss med 4 armer, mens ulykkesbelastede strekninger bør identifiseres blant 2-10 kilometer lange homogene vegstrekninger. Dette muliggjør estimering av det generelt forventede antall ulykker ved bruk av en ulykkesmodell.

Identifikasjonsprinsipper og kriterier

Identifikasjonen av ulykkesbelastede steder bør gjennomføres ved bruk av mer eller mindre avanserte modellbaserte metoder, ideelt sett den empiriske Bayes metode. Argumentet for dette er at modellbaserte metoder er best til foreta pålitelig identifikasjon av steder med lokale risikofaktorer, fordi det tas hensyn til systematisk og delvis tilfeldig variasjon i ulykkestallet.

Ulykkesbelastede steder bør identifiseres:

- På bakgrunn av det forventede antallet ulykker og ikke på bakgrunn av det registrert antall ulykker.
- Som steder som har et høyere forventet antall ulykker enn det normale antallet for liknende lokaliteter som et resultat av lokale risikofaktorer.
- Som steder hvor potensialet for ulykkesreduksjon (absolutt forskjell mellom forventet og normal ulykkestall) er større enn en predefinert størrelse.
- Eller som en bestemt prosent av vegnettet med størst innsparingspotensial (savings potential).

Idet det er flere ulykker på de ulykkesbelastede strekningene enn på ulykkespunktene bør skadegraden ved ulykkene være en integrert del av selve utpekningen i NSM, men ikke i BSM. Alvorlighet bør integreres ved vekting av samfunnsøkonomiske kostnader ved personskader i trafikken og det gjennomsnittlige antall personskader med forskjellig alvorlighet i de forskjellige nivåer for skadegrad.

Ulykkesanalyse – hypoteser og testing

Moderne tilnærmingsmåter for ulykkesanalysen består av to trinn:

1. Detaljert analyse av ulykkene med henblikk på å oppstille hypoteser om hvilke risikofaktorer som kan ha bidratt til ulykkene.
2. Test av disse hypotesene ved en dobbelt blind sammenligning av hvert ulykkesbelastet sted med et sikkert sted.

Ifølge de beste metoder bør analysefasen som et minimum bestå av følgende:

- En generell ulykkesanalyse
- Et ulykkesdiagram
- En trafikksikkerhetsinspeksjon
- Relevante analyser av trafikk og veg

I NSM bør den generelle ulykkesanalyse og ulykkesdiagrammet kombineres til et utvidet ulykkesdiagram.

Den generelle ulykkesanalysen og ulykkesdiagrammene bør sammenlignes med ulykkenes normale mønster på lignende steder.

Det skal også lages en aktiv og nedskrevet vurdering av hvorvidt stedene faktisk er ulykkesbelastede steder eller ikke.

Evaluering av tiltak

Evalueringen av effekten av de utførte tiltak bør gjennomføres som en empirisk Bayes før-etter-analyse, idet denne metoden kontrollerer for betydningen av generelle tendenser i antall ulykker, lokale endringer i trafikkmengden og regresjonseffekter i ulykkestall.

Hvis det ikke er mulig å gjøre en slik studie, bør evalueringen gjennomføres som en enkel før-etter-analyse, hvor det kontrolleres for generelle tendenser i antall ulykker, lokale endringer i trafikkmengden og regresjonseffekter i ulykkestall ved bruk av korreksjonsfaktorer.

Implementering – datainnhenting og modellering

For å kunne gjennomføre en oppdeling av vegnettet i klart definert grupper av vegelementer og homogene vegstrekninger er det nødvendig å samle inn data om ulykker, trafikkmengde, vegutformning og vegens omgivelser.

Disse dataene må være entydig stedfestet ved for eksempel bruk av kilometrering langs alle veger i vegsystemet. I tillegg skal data være umiddelbart kompatible med hverandre. Dette er en nødvendig forutsetning for å kunne utvikle en ulykkesmodell.

Ulykkesmodelleringen bør omfatte følgende trinn:

1. Avgjøre hva modellen skal brukes til, og om den skal utvikles i henhold til moderne tilnærmingsmåter eller beste metoder
2. Velge ut mulige avhengige og uavhengige variabler
3. Fremskaffe relevante data om disse variablene
4. Velge estimeringsmetode
5. Gjennomføre selve modellestimeringen i henhold til de tidligere gjennomførte valg
6. Evaluere modellens evne til at forklare og estimere den systematiske variasjonen i ulykkestallet
7. Foreta en empirisk Bayes estimering av det forventede antall ulykker på det enkelte sted

Ved utpekning av ulykkesbelastede strekninger er det anbefalt å inkludere alvorlighet. Dette gjør det nødvendig å estimere ulykkesmodeller for hver alvorlighetskategori. Denne estimeringen følger den samme prosedyre som ved estimering av en ulykkesmodell for alle ulykker. I tillegg trengs informasjon om gjennomsnittlige samfunnsøkonomiske kostnader ved personskader i trafikken.

Implementering – ulykkesanalyse

Ulykkesanalysen bør omfatte en sammenlikning med sikre steder eller det normale ulykkesmønstret. For å kunne gjøre dette må en:

1. Foreta en utpekning av sikre steder, etter samme prosedyre som for utpekning av ulykkesbelastede steder.
2. Matche hvert ulykkesbelastet sted så nøyaktig som mulig til et liknende sikkert sted.
3. Gjennomføre en supplerende innsamling av relevante data til analysen av hvert matchede par.
4. Utvikle en prosedyre som sikrer at den som foretar analysen ikke vet hvilket sted som er ulykkesbelastet og hvilket som er sikkert.

Tilsvarende må en estimere det normale ulykkesmønstret og utvikle en prosedyre for å matche hvert ulykkesbelastet sted til et med et relevant normalt ulykkesmønster.

Vedlikehold og oppdatering

En viktig del av implementeringen av de anbefalte metoder er endelig å utvikle en prosedyre for å sikre at data om metoder løpende vedlikeholdes og oppdateres og at det avsettes ressurser til dette arbeidet.

1 Introduction

1.1 Background

Black spot management (BSM) consisting of identification, analysis and treatment of black spots has a long tradition in traffic engineering in several countries in the European Union. It is still considered as a very essential part of the site-specific traffic safety work done by the road administration authorities.

In the last 5 to 10 years, the traditional black spot management has been supplemented with safety analysis of road networks also called network safety management (NSM) in more and more countries. The NSM differs from BSM by focusing on longer road sections of normally 2-10 kilometres, while the black spots seldom are longer the 0.5 kilometres.

However, the current approaches and quality of both BSM and NSM differ very much from country to country and the work can, in general, be characterised by a lack of standardised definitions and methods.

As work package 6 of the RIPCORD-ISEREST project the European Commission has funded a project named “Black Spot Management and Safety Analysis of road Networks – Best Practice Guidelines and Implementation Steps”. The objective of this project is to develop best practice guidelines for BSM and NSM and describe how these guidelines can be implemented.

The work in this work package will be documented in three reports. This report represents the third report. In the first report, “State-of-the-art Approaches to Road Accident Black Spot Management and Safety Analysis of Road Networks” (Elvik 2007) the approaches to BSM and NSM currently used in different countries are described and discussed. The state-of-the-art approaches to BSM and NSM are also described. A state-of-the-art approach is defined as the best currently available approach from a theoretical point of view. These state-of-the-art approaches to BSM and NSM are finally compared with the current approaches and it is concluded that there, in general, is a considerable gap between current practice and the state-of-the-art approaches. The current approaches in many countries thus need considerable development.

The second report is named “Best Practice Guidelines on Black Spot Management and Safety Analysis of Road Networks” (Sørensen 2007). Obviously, it describes the best practice guidelines for BSM and NSM. The difference between the state-of-the-art approaches and the best practice guidelines is that the state-of-the-art approaches are the best currently known approaches from a theoretical point of view, while the best practice guidelines are the best approaches from a more practical point of view when the data and resources for developing, implementing and using the methods are limited. In the report, a description is given of how classification of roadway elements, identification of black spots and hazardous road sections, accident analysis and evaluation of the treatment in BSM and NSM should be made from a practical point of view.

1.2 Objective and method

This report represents the last out of three reports. The objective of this report is to summarize all relevant aspects of the work package and describe the necessary steps to implement the guidelines for BSM and NSM.

Full implementation of the best currently available approaches will require access to quite extensive data and development effort and will therefore not be realistic in many countries in the near future. Thus, the objective is to describe some implementation steps that continuously bring you from the current methods used via the best practice guidelines to the state-of-the-art approaches as your data, resources and knowledge are increased. In other words, the objective is to describe how to come closer to ideal practices and how to remove the most glaring deficiencies in the currently used approaches.

As described the report summarises the results from the previous two reports. These reports are based on extensive literature surveys with focus on different methods for primary identification and analysis of black spots and hazardous road sections including references discussing how to assess if a method is "better" than others. In addition, the first report is based on empirical studies relying on data from Norway. Simulation has also been used.

1. **Data collection:** Collection of data on roads, traffic and accidents
2. **Dividing:** Dividing the road network into different road elements and sections
3. **Identification:** Ranking and identification of black spots / hazardous road sections
4. **Analysis:** In office analysis of accidents and on-site analysis
5. **Treatment:** Proposing of treatment for true black spots / hazardous road sections
6. **Pre evaluation:** Pre evaluation of proposed treatment
7. **Ranking:** Ranking of projects and location for treatment
8. **Implementation:** Implementation and operation of treatment
9. **Post evaluation 1:** Post evaluation of effect of treatment
10. **Post evaluation 2:** Post evaluation of traffic safety program

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Figure 1.1. Typical stages in BSM and NSM. Grey mark focus in this report.

1.3 Delimitation

BSM and NSM are typically divided into the 10 more or less independent stages described in figure 1.1. In the previously described state-of-the-art approaches and best practice guidelines for BSM and NSM in Elvik (2007) and Sørensen (2007) focus is on stages 2, 3, 4 and 9 – especially stage 3 and 4. These stages are marked as grey in figure 1.1. Thus, focus in this report will also be on these four stages. However, data collection is a very important part of the implementation of the recommended guidelines, and this stage will therefore also indirectly be treated.

1.4 Report structure

The structure of the report is illustrated in figure 1.2. The report is divided into five chapters. The chapter after this introduction is a discussion and clarification of the differences between state-of-the-art approaches and best practice guidelines, and it is specified why it is necessary and appropriate to distinguish between state-of-the-art approaches and best practice guidelines. Afterwards the use of state-of-the-art approaches and best practice guidelines in different stages of BSM and NSM are discussed. The relation between state-of-the-art approaches, best practice guidelines and different implementation steps is also clarified. Finally, the implementation of the combination of BSM and NSM are discussed.

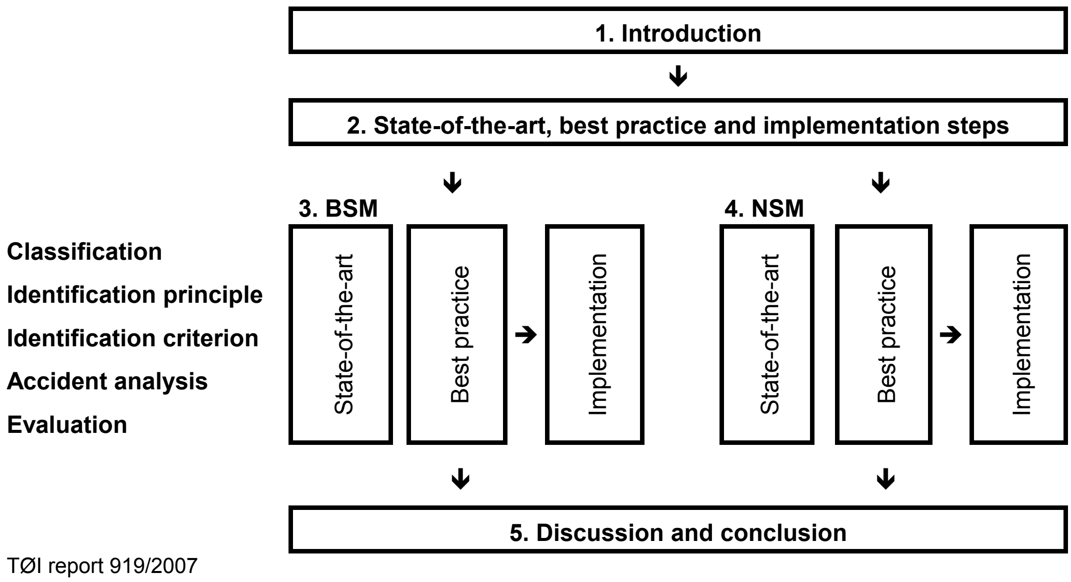

Figure 1.2. Diagram for the structure of the report.

The third and fourth chapter focus on BSM respectively NSM. For both chapters the state-of-the-art approaches, the best practice guidelines and the implementation steps are summarized and described with regard to classification of roadway elements, identification principle and criterion, accident analysis and evaluation of the treatment.

The last chapter summarizes, discusses and concludes in overall terms how to implement the recommended approaches for BSM and NSM.

2 State-of-the-art, best practice and implementation steps

This chapter summarizes overall differences between state-of-the-art approaches and best practice guidelines for black spot management (BSM) and network safety management (NSM). This includes a discussion of why it is necessary and appropriate to distinguish between state-of-the-art approaches and best practice guidelines. In addition, the use of state-of-the-art approaches and best practice guidelines in different stages of BSM and NSM are discussed. Afterwards the overall relation between state-of-the-art approaches, best practice guidelines and different implementation steps is clarified. Finally, the implementation of the combination of BSM and NSM is discussed.

2.1 Difference between state-of-the-art approaches and best practice guidelines

The primary differences between state-of-the-art approaches and best practice guidelines are summarized in table 2.1.

Table 2.1. Differences between state-of-the-art approaches and best practice guidelines.

	State-of-the-art approaches	Best practice guidelines
Nature	Idealistic	Pragmatic
Quality	Best from a theoretical point of view	Best from a practical point of view
Data	Comprehensive and interoperable	Limited
Resources	Comprehensive	Limited
Who	National or a regional public roads administration	Regional or local public roads administration

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State-of-the-art approaches are defined as the best currently known approach from a theoretical point of view, while best practice guidelines is the best approach from a more practical point of view.

To evaluate and determine what the best approach from a theoretical point of view the following four criteria are used:

1. **Random fluctuations:** It should control for random fluctuations in the number of accidents by relying on the expected number of accidents and not the recorded number.
2. **Systematic variation:** It should account for as many as possible of the factors relating to traffic volume, traffic control and road design that are known to influence road safety by use of accident prediction models.

3. **Local risk factors:** It should identify sites at which local risk factors related to road design and traffic control make a substantial contribution to accidents resulting in higher expected number of accidents than normal the expected number for similar locations.
4. **Severity:** Severity should be taken into account in a systematic way, if road safety policy seeks to prevent the most serious accidents.

In table 2.1 it is specified that data are comprehensive and interoperable in the state-of-the-art approaches. This means in principle that all relevant data about accidents, traffic volume, road design and the surrounding environment are relative easily available, have a high or sufficient quality, are unambiguously located on the road network and are immediately interoperable with each other. In contrast, the use of best practice guidelines is based on limited data regarding both quantity, quality and interoperability.

Another characteristic feature of the state-of-the-art approaches is that there in principle are comprehensive resources with regard to time, money, personnel and professional expertise to develop, implement and afterwards use approaches that are equivalent to the state-of-the-art approaches. In contrast, developing, implementing and using best practice guidelines are based on limited resources.

The development, implementation and use of state-of-the-art approaches will typically be possible for only a national or maybe a regional public roads administration with an overall responsibility for the traffic and road sector. However, implementation and use of the best practice guidelines can to a greater degree probably be done by regional and maybe local public road administrations.

2.2 Why state-of-the-art and best practice guidelines

As described in this report the state-of-the-art approaches are defined as the best currently available approaches from a theoretical point of view if you in principle have no limitations with regard to accident, traffic and road data and resources for developing, implementing and using the approaches.

However this is only in rare instances the case, and it is better to have and use some best practice guidelines rather than refrain from doing anything because the demands for doing the state-of-the-art approaches can not be satisfied.

2.3 Use of state-of-the-art and best practice guidelines

Obviously it is preferable that the state-of-the-art approaches are used for all stages of BSM and NSM, but this may not always be possible due to deficient data and resources.

When state-of-the-art approaches are not used for all stages it is recommended that the approaches as minimum are used for one of the stages, because it to a certain extent can compensate for the lack of use in other stages. In fact, the use of state-of-the-art approaches in one stage is even more important, when the state-of-the-art approaches are not used in the other stages. This applies especially for the identification and analysis stages with regard to ensure that it is only true black spots and hazardous road sections that are treated in the BSM and NSM (Elvik 2006, Sørensen 2006). The point can be summarized in the following way:

- The use of more primitive methods for identifying black spots and hazardous road sections places additional burdens on the analysis of accidents to sort out falsely identified locations.
- The use of more primitive method for analysing black spots and hazardous road sections places additional burdens on the identification stage to avoid many false positives that maybe will not be sorted out in the analysis stage.

2.4 Implementation of state-of-the-art and best practice

The development, implementation and use of either state-of-the-art approaches or best practice guidelines in a national or maybe a regional context depends on the data and resources available. This means that the limits of the data and the resources determine how close the methods can come to the best practice guidelines and state-of-the-art approaches. The more data and resources the more close the methods can come to the best practice guidelines and the state-of-the-art approaches. A full implementation of the state-of-the-art approaches requires access to quite extensive data and resources.

The implementation of the recommended methods can in general be characterized as a stepwise process moving from the current methods in use via the best practice guidelines towards the state-of-the-art approaches at the top of the ladder as the data are improved and the resources increased. This is illustrated in figure 2.1.

Note that the first or second steps taken are as important as the final step. In fact can it from a more practical point of view be argued that the first steps are the highest and that the steps are getting smaller and smaller the closer to the state-of-the-art approaches you are getting.

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Figure 2.1. The stepwise process moving towards state-of-the-art approach as the data are improved and the resources for developing and use are increased.

As described before the development and implementation of state-of-the-art approaches and partly the best practice guidelines is so data and resource demanding that it only can be done by a national or maybe a regional agency, which has the overall responsibility for the traffic and road sector. In this context, development means adjustment of state-of-the-art approaches to national and regional conditions. Depending of the current organisation of road safety management it means that as minimum the development and implementation have to be centralized. This is also illustrated in figure 2.1. Afterwards the methods can maybe be used by more regional or local road authorities.

2.5 The combination of BSM and NSM

In the following BSM and NSM are described independently. However, it should be noted that several of the implementation steps are the same for the two approaches especially with regard to data. Thus data about the accidents, traffic volume and road design that have a high quality, are unambiguously located on the road network and immediately interoperable with each other are a necessary condition for implementing both BSM and NSM according to the recommended methods. Data collected for implementation of BSN can therefore also be used in the implementation of NSM.

Another question is if state-of-the-art approaches or best practice guidelines for BSM and NSM should be implemented at the same time, or if the resources should be focused on one of the approaches at first. The answer to this question depends of the following parameters:

- The tradition in the traffic safety work
- The current accident level
- The nature of the accidents and the normal accident pattern
- The nature of the road network and the traffic
- The traffic safety policy including objectives and focus
- The staff and economic resources

This means that you cannot give one common answer to this question, which has validity for all the countries and road administrations in all Europe. However, it is possible to conduct some more general discussions and recommendations.

Among the European countries, you see different tendencies. In some of the safest countries such as Finland, Sweden and England, which have made BSM on the public road network since the 1960s the BSM have been replaced with NSM, because all the black spots have been identified and treated (European Commission 2003). In addition, France has also decided to stop doing BSM and instead focus on NSM (Setra 2003).

In other of the safest countries such as Norway, Denmark and Germany, which also have made BSM for many years, the BSM have not been replaced but only supplemented by NSM (Ragnøy et al. 2002, Sørensen 2006, German Road and Transportation Research Association 2003, 2006).

Finally, some countries have just made BSM for few years or are planning to start making BSM on the public road network. This includes Italy, Greece and probably several of the east European countries (European Commission 2003).

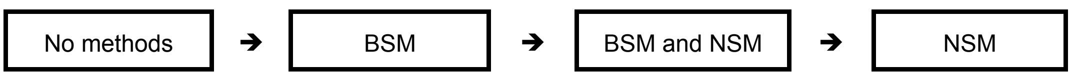

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Figure 2.2. The process from doing BSM to doing both BSM and NSM to doing NSM.

The observed process is illustrated in figure 2.2. This process of implementing BSM and NSM is also recommended in this project. Thus, it is recommended to start with implementation of BSM. The arguments for doing this are:

- It is complicated to implement BSM and NSM at the same time, if there is no long tradition for this work.
- BSM is immediately more understandable than NSM and there is a more common understanding of BSM than NSM.
- Based on experience there are many black spots when implementing BSM the first time and several years after having implemented BSM. This means that all resources for site specific traffic work can be used effectively on the black spots.
- When implementing BSM the black spots typically have a lot of accidents and clear accident patterns that often can be treated by use of relatively low-cost measures. This gives a very cost effective traffic safety work.
- From an ethical point of view, you should focus on the most hazardous and dangerous sites in the traffic safety work.

After having focused on BSM in a period of time it is recommended to supplement this work with NSM. The arguments for this are the following (Ragnøy et al. 2002, Sørensen 2006):

- When BSM has been done for several years, it will more or less become a routine. This means that there will be energy to develop, implement and use a new approach such as NSM.
- Common knowledge about an approach as BSM among both professionals, non-professionals, politician and the media are important for the success of the work and it should therefore be continued as long as benefits are greater than the costs.
- When you know and understand the philosophy and procedure in BSM fully it is easier to get to know and understand the philosophy and procedure in NSM.
- BSM should be continued as long it has a potential to contribute to improved traffic safety, but when all the most "black" spots have been identified and treated the potential of the work will gradually be smaller. Hence, it is necessary to supplement with other approaches as NSM.

After having focusing on BSM for many years and maybe supplemented this with NSM it is recommended to start focusing primarily on NSM. The primary reason for that is that all the black spots in principle will have been identified and treated when BSM has been done for many years and the costs of continuing the work will hence probably be greater than the benefits. In this context, it is assumed that road safety audits (RSA) have been implemented, thus new black spots should in principle not arise.

The case with the combination of BSM and NSM is presumably the most relevant situation for most of the European countries now or within a short period of time. At the same time, it is the most complex of the three described situations. It is therefore relevant to raise the question about how the two approaches should be combined. However, with exception of Sørensen (2006) the question has not been raised or examined in any projects or discussed in any public literature.

Sørensen (2006) states that BSM and NSM can be combined in the following three ways:

- *Independently:* BSM and NSM are carried out completely independently. This means that no results from one approach and how these can influence the other approach are taken into consideration when the other approach is carried out.
- *Partly dependently:* BSM and NSM are carried out partly dependently. This means that some of the results from one approach and how these can influence the other approach are taken into consideration when the other approach is carried out.
- *Fully dependently:* BSM and NSM are carried out fully dependently. This means that all results from one approach and how these can influence the other approach are taken into consideration when the other approach is carried out.

It is recommended that the black spot identification are performed first independently of NSM because the methods for black spot identification after all have the longest tradition and therefore this method should not be complicated unnecessarily – especially not when best practice guidelines or state-of-the-art approaches are implemented at the same time. In addition, it is most logical in terms of terminology to start with the black spot identification and then afterwards make the identification of hazardous road section or grey road sections, which they are called in Denmark.

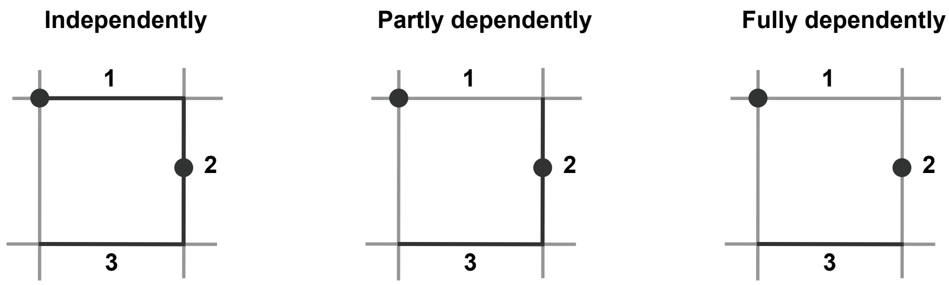

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Figure 2.3. Illustration of how the identification of hazardous road sections (illustrated by black lines) on a fictitious road network are influenced by the result of the identification of black spots (illustrated by black spots) if the identification in NSM is done independently, partly dependently or fully dependently of identification in BSM. In the first case road section 1 and 2 are identified as hazardous due to the black spots on these. In the second case accidents on black spots in large intersections are subtracted, which means that road section 1 is not identified as hazardous. In the last case all accidents on black spots are subtracted, which means that neither road section 1 nor road section 2 are identified as hazardous. In the last case, it is only road section 3 that is identified as hazardous.

After the black spot identification is performed, the identification of hazardous road sections can be made in one of the three described ways. The three cases are illustrated on a fictitious road network in figure 2.3. The most easy way is to make an independent identification. However, you risk that the accidents on the identified black spots also influence the result of the identification of hazardous road sections. In other words some hazardous road sections are only being identified because there are one or more black spots on them. This means that you in a way have two different approaches to identify more or less the same locations.

The solution to this problem is to make an identification of hazardous road sections that is partly or fully dependent of the results from the black spot identification.

In the fully dependent identification all the accidents on the identified black spots are subtracted from the total, and in the partly dependent identification it is only the accidents on some of the black spots that are subtracted. It is suggested to subtract the accidents on black intersections. There are several arguments for that (Sørensen 2006):

- It is rational to divide the road safety work into intersection and road section based traffic safety management because there in general are different traffic safety problems and possible measures in intersections and on road sections.
- It is evident that all road section based accidents are included in the road section based identification, because these accidents could in principle occur anywhere on the concerned road section.
- The identification of short black road sections has been criticized in Denmark because the road sections are too short to allow a reliable identification of accident patterns. This problem can probably be solved by including the short black road sections in the longer hazardous road sections.
- As described in Sørensen (2007) the division of the road system should be based on large intersections and these are therefore not included in the road network. Some of these intersections are maybe black spots. In this context, it will not be logical if only some of the black intersections are excluded, and hence all black spots should be excluded.
- It should be possible to subtract the accidents on all black intersections in a relative easy and automatic way.

Based on these arguments it will be recommended to make an independent black spot identification and then make a partly dependent identification of hazardous road sections excluding the accidents on black intersections.

2.6 Summary

State-of-the-art approaches are defined as the best currently known approach from a theoretical point of view, while best practice guidelines is the best approach from a more practical point of view. The main differences are that data about accidents, traffic and road design and resources for method development and implementation are comprehensive in the state-of-the-art approaches, while the use of best practice guidelines is based on limited data regarding to quantity, quality and interoperability and limited resources regarding money and personnel.

Obviously, state-of-the-art approaches are to prefer, but accident, traffic and road data and resources for developing, implementation and use of the approaches are only in rare instances comprehensive. Thus, the best practice guidelines are described as it is better to use these rather than refrain from doing anything because the demands for doing the state-of-the-art approaches can not be satisfied.

It is also preferable that the state-of-the-art approaches are used for all stages of BSM and NSM, but that will not always be possible. However, it is recommended that the approaches as minimum are used for one of the stages, because it to a certain extent can compensate for the lack of use in other stages.

The implementation of the recommended methods can in general be characterized as a stepwise process moving from the current methods in use via the best practice guidelines towards the state-of-the-art approaches at the top of the ladder as the data are improved and the resources increased.

The development and implementation of state-of-the-art approaches and partly the best practice guidelines is so data and resource demanding that it probably only can be done by a national or maybe a regional agency, which has the overall responsibility for the traffic and road sector. Afterwards the methods can be used by more regional or local road authorities.

This report deals independently with both BSM and NSM. However, several of the implementation steps are the same for the two approaches especially with regard to data. Data collected for implementation of BSN can therefore also be used in the implementation of NSM.

If there is no long tradition for site specific traffic safety work it is recommended to start with implementation of BSM. After a period of time this should be supplemented with NSM. Finally, when all black spots have been identified and treated and new black spots are hopefully prevented from arising due to road safety audits (RSA), the focus should solely be on NSM.

The case with the combination of BSM and NSM are presumably the most relevant situation for most of the European countries now or within a short period of time. In this case it is recommended to make an independent black spot identification and subsequently make a partly dependent identification of hazardous road sections excluding the accidents on black intersections.

3 Black spot management

This chapter summarize the state-of-the-art approaches and the best practice guidelines for black spot management (BSM) with regard to classification of roadway elements, identification principle, identification criterion, accident analysis and evaluation of the black spot treatment. It is only the key elements that are summarized. Thus, see Elvik (2007) for further clarification for the elements in the state-of-the-art approach and Sørensen (2007) for further clarification for the elements in the best practice guidelines.

After the description of the different elements of the state-of-the-art approaches and the best practice guidelines it is discussed and recommended how the approaches can be implemented as an integrated part of the road administration authorities' site specific road safety management.

3.1 What is black spot management?

Before the description of the state-of-the-art approaches, the best practice guidelines and the implementation steps it is shortly explained what BSM is and how it currently is done in different European countries.

Note that black spots sometimes are referred to as hazardous road locations, accident prone locations, dangerous accident locations, problem locations, hot spots or sites with promise. In this report the term black spots is used.

3.1.1 Definition and philosophy

No standard definition exists of black spots (Hauer 1996, Elvik 2004). However, based on an OECD report (OECD Road Research Group 1976) and more recent work (Persaud et al. 1999, Hauer et al. 2002, Vistisen 2002, Overgaard Madsen 2005, 2005a) a distinction can be made between the following common definitions of black spots:

1. Numerical definitions

- Accident number
- Accident rate
- Accident rate and number

2. Statistical definitions

- Critical value of accident number
- Critical value of accident rate

3. Model-based definitions

- Empirical Bayes
- Dispersion value

An example of a simple numerical definition is the official Norwegian definition of a black spot: "A black spot is any location with a maximum length of 100 metres, at which at least four injury accidents have been recorded during the last five years" (Statens vegvesen 2006). This definition does not make any reference to traffic volume or to the normal number of accidents, nor does it specify the type of location considered.

An example of an accident rate definition of a black spot would be: "A black spot is any location as for example a junction, a section or a curve at which the number of injury accidents per million vehicles or vehicle kilometres, estimated for the most recent four years, exceeds the value of for example 1.5". This definition differs from the simple accident number definition by taking account of traffic volume, and thus implicitly referring to what is regarded as a normal number of accidents.

A statistical definition of a black spot relies on the comparison of the recorded number of accidents to a normal number for a similar type of location. For example, a junction will be classified as a black spot if the recorded number of accidents in a specific period is significantly higher than the normal number of accidents for this type of junction. Depending on how the normal number of accidents is estimated, a statistical definition may come close to a model based definition of a black spot.

Model-based definitions of black spots are derived from a multivariate accident prediction model. An example is the Empirical Bayes (EB) definition of a black spot given by Persaud et al. (1999). Models were developed for intersections and road sections, and the 20 highest ranked locations were identified according to the EB estimate of the expected number of accidents.

Persaud et al. (1999) tested the performance of two interpretations of a model-based Empirical Bayes black spot concept. According to the first definition, black spots were simply those 20 intersections that had the highest expected number of accidents, according to the EB-estimate. According to the second definition, borrowed from McGuigan (1981), a black spot was defined in terms of the potential for accident reduction, defined as the difference between the EB-estimate of the expected number of accidents for a specific site and the model estimate of the normal expected number of accidents for similar sites.

From a more theoretical point of view black spots can be defined as any location that (Elvik 1988, 2007):

1. Has a higher expected number of accidents,
2. Than other similar locations,
3. As a result of local risk factors.

All three elements of the definition are needed. With respect to the first element, black spots should be defined in terms of the long-term expected number of accidents, not in terms of the recorded number of accidents. It does not make sense to regard a location as abnormally hazardous simply because a high number of accidents happened to be recorded during a specific period. Observed variation in accidents is always a mixture of random and systematic variation, and it is sources of systematic variation we are looking for in safety analyses.

As far as the second element is concerned, black spots should always be identified as members of a certain population of sites that are more or less similar to each other. Examples include intersections with a given number of legs, road sections of a given length or horizontal curves with radius in a certain range. The similarity of locations can also be assessed according to the values for explanatory variables used in accident prediction models. Similar sites would then typically be sites that have nearly the same traffic volume, the same speed limit, the same number of lanes, and so on, for all variables that are included in the accident prediction model.

However, no definition of a population of sites and no accident prediction model will be exhaustive in the sense that these definitions or models correctly identify all sources of systematic variation in the number of accidents. If they did, all remaining variation would by definition be random only. In that case a high expected number of accidents would be regarded as "normal" in the sense that it would be fully explained in terms of the classification of sites or the accident prediction model fitted. Accidents are, however, influenced by a very large number of factors, some of which are local. Thus, the third element of the definition, stating that a higher expected number of accidents should be attributable to local risk factors is also needed.

Based on the definition the basic philosophy for BSM can be clarified. Thus, the philosophy is to use the accident history to identify locations with local risk factors that not are immediately visible for the road users and that are related to the local detailed road layout and traffic behaviour. These locations can be treated relatively inexpensively because it is only the detailed road layout and traffic behaviour that have to be changed and not the general road layout. Therefore you get a lot of value for money used in terms of traffic safety. The nature of BSM can be summarized as local, retrospective and remedial.

3.1.2 Stages in BSM

BSM can be divided into 10 more or less independent stages as described in figure 1.1. This can also be summarized in the following three activities:

1. Definition and identification of black spots
2. Analysis of accidents and risk factors at black spots, designed to identify factors contributing to accidents and propose treatments
3. Implementation and evaluation of treatments at black spots

BSM starts with a systematic collection of data that enable the identification of sites that have developed into black spots. Once black spots have been identified, accidents are analysed in order to find a common pattern of accidents and factors that contribute to accidents. A visit to each site identified as a black spot is usually part of the process of analysis.

The objective of a detailed analysis of accidents and other relevant data is to identify factors contributing to accidents that may be amenable to treatment. If this analysis is not successful, it will be concluded that the black spot is likely to be false and no treatment will then be implemented. If, on the other hand, a treatment believed to be effective is found, it should be implemented and its effects evaluated.

3.1.3 Current identification methods and definitions

In Elvik (2007, 2008) a survey was conducted to describe how black spots are identified in the eight European countries: Austria, Denmark, Flanders, Germany, Hungary, Norway, Portugal and Switzerland. These are summarized and discussed in the following.

Austria

A black spot is any location that satisfies one of the following two criteria:

1. Three or more similar injury accidents within three years and a risk coefficient R_k of at least 0.8. The risk coefficient is calculated as follows:

   $$R_K = \frac{U}{0.5 + 7 \text{ x } 10^{-5} \text{ x AADT}}, \text{ where:}$$

   AADT = Annual Average Daily Traffic

   U = Number of injury accidents during three years

2. Five or more accidents (including property damage only) of similar type during one year. Since 1995 property damage accidents are not recorded. Hence identification of black spots primarily relies on the first definition.

To identify black spots, a sliding window with a length of 250 metres is applied. The window is moved along a road and flags each location where one of the two criteria for a black spot is met. The principle of the sliding window approach is illustrated in figure 3.1. An accident typology consisting of ten different types of accident has been developed for the purpose of identifying similar accidents (Austrian Guideline Code for Planning, Construction and Maintenance of roads 2002).

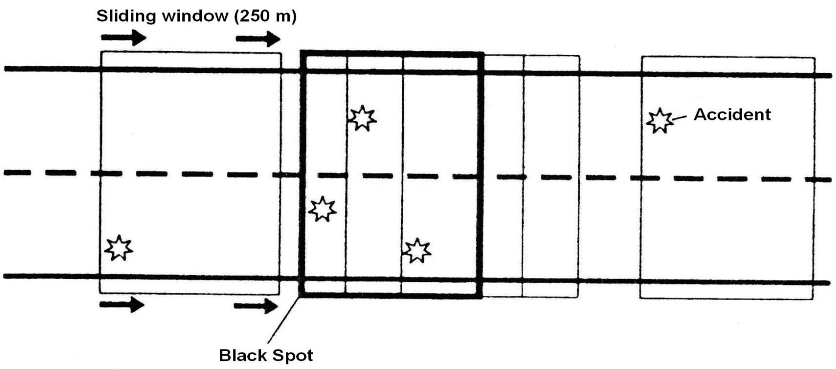

Figure 3.1. Identification of black spots in Austria by sliding window approach (Austrian Guideline Code for planning, Construction and Maintenance of roads 2002).

Denmark

The identification of black spots relies on a fairly detailed classification of the road system into various types of road sections and various types of intersections (Vistisen 2002, Overgaard Madsen 2005). To identify a black spot, a test based on the Poisson distribution is used. The minimum number of accidents for a site to be considered as black is four accidents recorded during a period of five years. The level of significance used in the statistical test is 5%. Thus, suppose the normal number of accidents for a location has been estimated to 2.8 during five years and that five accidents have been recorded. Applying the Poisson distribution, the probability of observing at least five accidents given that the mean number is 2.8 can be calculated to 0.152, which means that this location would not be classified as black.

As far as road sections are concerned, black sections are identified by means of a sliding window approach. The size of the window varies, depending on the normal number of accidents for a section.

Flanders

The following definition of a black spot is applied (Geurts 2006), based on police reports of accidents: Each site where in the last three years three or more accidents have occurred, is selected. Then, a site is considered to be black when its score for priority (S), calculated using the following formula, equals 15 or more:

$S = LI + 3 \cdot SI + 5 \cdot DI$, where

LI = total number of slight injuries

SI = total number of serious injuries

DI = total number of deadly injuries

A sliding window with a length of 100 metres is applied to identify black spots.

Germany

Black spots are identified by means of maps showing plots of accidents. A period of either one year or three years is used to identify black spots (German Road and Transportation Research Association 2006).

If one year is used, a location is classified as black if five accidents of a similar type, irrespective of severity have been recorded at a location extending for no more than about 100 metres. An elaborate accident typology has been developed to help determine if accidents are of a similar type or not.

Using a three year period, a black spot is defined as any location where five or more injury accidents have been recorded or any location where three or more serious injury accidents have been recorded.

Hungary

Two definitions of black spots are used. Outside built-up areas, a black spot is defined as a location where at least four accidents have been recorded during three years on a road section no longer than 1000 metres. Inside built-up areas, a black spot is defined as a location where at least four accidents have been recorded in three years on a road section no longer than 100 metres.

Search for black spots is made by using the sliding window approach. The window is either 1000 metres or 100 metres wide.

Norway

In Norway, a distinction is made between black spots and black sections. A black spot is any location with a length of not more than 100 metres where at least four injury accidents have been recorded in the last five years. A black section is any road section with a length of not more than 1000 metres where at least 10 injury accidents have been recorded during the last five years. The period used to identify black spots or black sections was recently extended from 4 to 5 years (Statens vegvesen 2006).

Black spots and black sections are identified by applying a sliding window, which is fitted to the location of the accidents. Black sections will often consist of several black spots that are located near one another.

Portugal

Two definitions of black spots are currently used in Portugal: one was developed by the Traffic Directorate (DGV); the other was proposed by LNEC.

According to the definition of DGV, a black spot is a road section with a maximum length of 200 metres, with five or more accidents and a severity indicator greater than 20, in the year of analysis. The severity index is calculated by the following weighted sum:

$$100 \cdot \text{number of fatalities} + 10 \cdot \text{number of serious injuries}$$
$$+ \text{Number of slight injuries.}$$

Detection is carried out using a sliding window moving along the road.

An alternative method was proposed by LNEC in 1997 and tested in 1998. According to this method, a black spot is a geographical area where the expected number of accidents is greater than in similar areas, due to the influence of road characteristics peculiar to the area. In practice this definition is applied differently to intersection and non-intersection accidents.

As far as non-intersection accidents are concerned, different minimum road section lengths are used for single carriageway roads and dual carriageway roads: 250 metres minimum length is used in the first case, 500 metres in the second. The road network has been divided into 6 classes of road. For each class of road, a unique accident prediction model is fitted to accident data for a five year reference period. In each year, observed accident data from the previous five years are combined with the corresponding accident prediction model to estimate the expected number of accidents. Depending on the road class, the worst 1/1000 or 2/1000 cases are selected for detailed safety diagnosis and possible intervention.

Switzerland

A black spot is defined as any location where the recorded number of accidents is “well above” the mean number of accidents at comparable sites. Comparable sites are defined by classifying the road system into various types of sections and intersections. For each group, accident rates are estimated. Based on the accident rates, critical values for the minimum recorded number of accidents during a period of two years for a site to be identified as a black spot have been developed.

For motorways, the critical accident count is 10 for all accidents, four for injury accidents and two for fatal accidents.

For rural roads, the critical values are eight for all accidents, four for injury accidents and two for fatal accidents.

For intersections in urban areas, the critical values are 10 for all accidents, six for injury accidents and two for fatal accidents.

The length of a black spot, except for intersections, varies between 100 and 500 metres, depending on traffic volume.

Comparison of current methods

Table 3.1 provides an overview of identification methods and definitions of black spots presented above in terms of six different characteristics.

Table 3.1. Overview of identification methods and definitions for black spots in eight selected European countries.

	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 accident period
Austria	No	Yes, 250m	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 4 accidents	No	5 years
Flanders	No	Yes, 100m	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, 100m or 1000m	No	Recorded, minimum 4	No	3 years
Norway	Not when identifying black spots	Yes, 100m (spot) or 1000m (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 year 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

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Black spots are, in most countries, not identified by sampling units from lists of elements belonging to a population of sites. In most countries, black spots are identified by applying a sliding window to the locations of accidents, and fixing the position of the window at points where it contains the local maximum number of accidents. In Germany accident maps are used, but in practice this may come to nearly the same thing as using a sliding window, since black spots are identified according to the locations of accidents. Denmark uses a sliding window for road sections, but not for junctions. Portugal uses a sliding window for one of its definitions of black spots, not for the other.

A black spot is generally taken to be a site that has an abnormally high number of accidents. This definition suggests that black spots cannot be meaningfully identified without some reference to the normal level of safety. Some of the currently employed definitions of black spots in European countries make an explicit reference to the normal level of safety, but surprisingly not all definitions make such a reference. References to the normal level of safety are generally made by comparing the number of accidents at sites identified as black to the number of accidents expected for similar sites, estimated by means of accident prediction models or by referring to a set of normal accident rates.

All countries identify black spots in terms of the recorded number of accidents. The only exception from this is the definition developed by LNEC in Portugal, which relies on the empirical Bayes method. Defining black spots in terms of the recorded number of accidents is perhaps not very surprising, as the long-term expected number of accidents cannot be observed, only estimated. In some countries, tests are performed to determine if the recorded number of accidents is significantly higher than the normal number expected for similar sites. Presumably, sites that do not pass this test are deleted from the list of black spots and not treated as abnormal.

Some definitions of black spots consider accident severity, other definitions do not. If accident severity is considered, there is no standard way of doing so. Three different approaches can be identified. One approach is to set a more stringent critical value for the number of serious injury accidents than for all injury accidents when identifying hazardous road locations. A second approach is to apply weights to accidents at different levels of severity. A third approach is to estimate the costs of accidents. These costs vary according to injury severity; hence, costs will be higher at sites that have a high proportion of fatal or serious injury accidents.

The length of the period used to identify black spots varies from one year to five years. A period of three years is frequently used. Research by Cheng and Washington (2005) shows that the gain in the accuracy of identification obtained by using a longer period of three years is marginal and declines rapidly as the length of the period is increased. There is little point in using a period of more than five years.

3.2 Classification of roadway elements

This section describes how the road system should be divided into smaller roadway elements, and what should be done to implement this recommendation.

3.2.1 State-of-the-art approach

Firstly, black spots should be identified by reference to a clearly defined population of roadway elements whose members can be enumerated and for which the general expected number of accidents can be estimated. These road elements can for example include sections of a specified length, curves with radius within a certain range, bridges, tunnels, three-leg junctions or four-leg junctions. This allows theoretical probability distributions for accidents to be fitted to the empirical distribution and allows precise statistical criteria of deviancy to be formulated.

Secondly, the use of a sliding window approach to identifying black spots is discouraged. The reason is that use of a sliding window that determines the location of a black spot according to the location of the accidents, rather than by sampling locations from a known sampling frame has been found to greatly inflate the number of false positives.

Table 3.2. Effects of using a sliding window approach on the number of black spots identified (Elvik 1988a, 2007).

Number of accidents	Fixed 1-kilometre sections, 4 years	Sliding 1 kilometre sections, 4 years	Fixed 4-kilometre sections, 1 year	Sliding 4-kilometre sections, 1 year
0	19	Not defined	11	Not defined
1	19	9	25	9
2	19	13	23	12
3	18	11	16	16
4	10	11	11	12
5	7	7	6	8
6	3	4	5	5
7	3	3	3	5
8	1	0		0
9	0	2		0
10	0	2		1
11	1	0		
12		0		
13		0		
14		1		
Total sections	100	65	100	68
Mean per section	2.44	3.87	2.44	3.59
Variance	4.37	6.59	3.19	3.57

This is shown empirically by Elvik (1988a, 2007). Table 3.2 reproduces some of his findings. The first column shows the distribution of 100 1-kilometre road sections by the number of accidents. The mean number of accidents was 2.44. The variance was 4.37. The distribution does not differ significantly from a negative binomial distribution.

The next column shows the results of applying a sliding window of length 1-kilometre to the same 100 kilometres of road network. It is seen that the tail of the distribution becomes substantially longer.

If sections with five or more accidents are defined as black, there are 15 such sections in the population of fixed sections, but 19 according to the sliding window approach. Using the sliding window artificially inflates the number of black sections, and makes each section look more black than it really is.

The findings are the same when fixed and sliding 4-kilometre sections are compared. The number having five or more accidents is 14 when fixed sections are used, 19 when sliding sections are used.

Theoretical work by Hauer and Quaye (1990, 1993) confirms these findings. Hauer and Quaye applied a sliding window approach to a fictitious population of sites of which 900 sites had an expected number of accidents of one, 90 had an expected number of accidents of two and 10 had an expected number of three.

Within each group, the registered number of accidents was assumed to be Poisson distributed around the mean value. A critical value of five accidents was used to identify deviant sites.

If fixed sections are used, it can be estimated that 10 sites will be identified as positive. If, however, a sliding window is used, 34 sites will be identified, of which the great majority will be safer than average. Thus, using a sliding window greatly inflates the number of false positives identified as black spots.

However, it should be noted that there are some problems by using the recommended approach of dividing the road system into smaller elements. This is probably the reason that the sliding window approach has been developed and is used in several countries as Austria, Denmark, Flanders, Hungary, Norway and Portugal.

The problem relates especially to road sections. If these road sections are divided into not overlapping segments with a length of for example 0,5 kilometre there is a risk that the division will not correspond to the accident pattern. Local accident peaks might be divided between two segments and thus not identified as a black spot. In other words, you have a problem with false negative. To avoid this problem the segment length can be reduced, but this increase the risk of random accidents peaks being identified as black spots (Hauer et al. 2002).

3.2.2 Best practice guidelines

With regard to best practice guidelines for dividing the road system into smaller roadway elements, the same recommendation as in the state-of-the-art approach is made. The argument is the following:

- Dividing of the road system into clearly defined populations of roadway elements has been found to be less resource demanding than using a sliding window approach, especially with regard to development of method (Hauer et al. 2002, Andersen and Sørensen 2004, Pedersen and Sørensen 2007).
- The principle is considered to be more simple and easy to understand than use of a sliding window approach.
- When black spots are to be identified by use of more or less sophisticated model based identification methods as recommended in chapter 3.3 it is immediately necessary that the road system is divided into clearly defined roadway elements.

3.2.3 Implementation steps

To identify black spots by reference to a clearly defined population of roadway elements it is obviously necessary to make a more or less detailed division and classification of the entire road network into different roadway elements. The division and classification will vary form country to country and maybe also from region to region.

In principle, the division should consist of a division of roadway elements in urban and rural areas and a division in various types of intersections and various types of road sections. Table 3.3 summarizes what roadway elements that can be relevant to divide the intersections and road sections into. To make it possible to make a model based identification of black spots these road elements should afterwards be subdivided into smaller units with different detailed road layout. This is clarified in chapter 3.3.4.

Table 3.3. Various types of intersections and road sections in urban and rural areas.

Urban area	Rural area	Urban area	Rural area
Intersections		Road sections	
– Four-leg junctions		– Straight sections of a specified length	
– Three-leg junctions		– Horizontal curves with different radius	
– Roundabouts		– Bridges	
– Access ramps		– Tunnels	

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In order to make this division possible it is necessary to have a clearly defined method to locate all these roadway elements and know precisely where they start and end.

This can be done in several ways as for example by use of global position system (GPS) or number of houses. However, one of the most common methods used which is also recommended is to divide the road network into roads with unique road numbers, and afterwards make a stationing along each of these roads as shown in figure 3.2. The level of detail in this stationing should be kilometre and metre, so you for example know that a given intersection is located at kilometre 1.108.

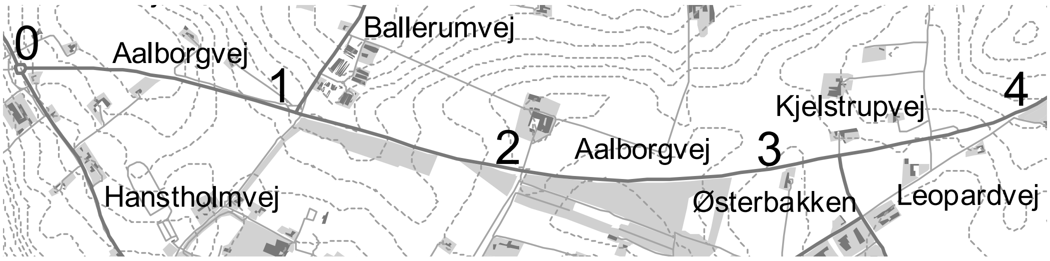

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Figure 3.2. An example on a stationing along a road section. Numbers on the map indicate the kilometre. By use of this stationing, it is for example possible to locate the intersection between Aalborgvej and Ballerumvej in kilometre 1.108.

3.3 Identification principles

This section reviews how black spots should be identified, and what should be done to implement this recommendation. The chapter begins with some general recommendations concerning both the state-of-the-art approach and best practice guidelines.

3.3.1 General recommendations

Overall identification principles can be divided into accident based and not accident based principles. In addition the accident based principles can be divided into model based and not model based principles. Transverse to this division you can identify principles you could call accident specific principles. The not accident based principles can be divided into quantitative and qualitative principles. Finally, the different principles and the methods can be combined in several ways (Sørensen 2006, 2007). This is illustrated in figure 3.3.

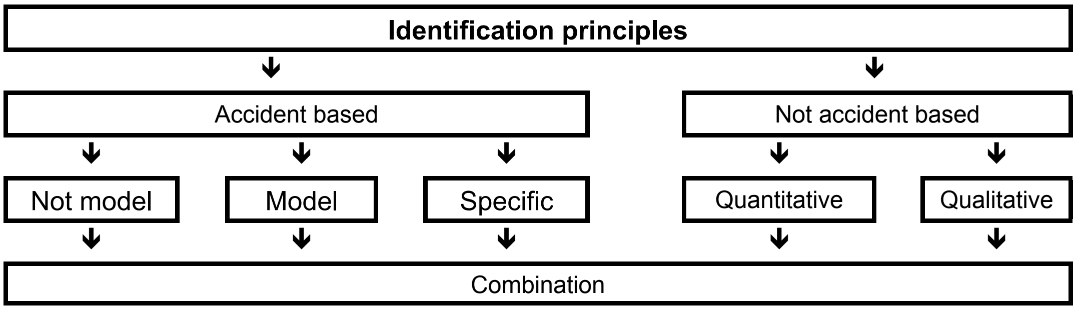

Figure 3.3. The five overall identification principles (Sørensen 2006, 2007).

The accident based methods rely on data from the official accident statistics. However, several studies show that these statistics both have a low and unbalanced coverage in comparison with the real situation in most European countries (Elvik and Mysen 1999). This means that there is a risk of focusing on some wrong locations and problems in the BSM. See an example of a study from Denmark in Andersen and Sørensen (2004).

To avoid this problem many attempts of not accident based identification have been made in recent times especially in North America (Leur and Sayed 2002, Hummer et al. 2003).

Despite problems with deficient accident databases the recommendation is that, identification of black spots should be accident based, at least to some extent. This is recommended for several reasons:

– Many attempts of not accident based identification are made, but satisfactory methods for not accident based identification have not yet been developed and implemented and these methods thus need further development and evaluation (Hauer 1996, Sørensen 2006). Thus, accidents must still be considered as the best indicator for black spots.

– Despite Hummer et al. (2003) saying the opposite, we expect that the quality and quantity of accident databases will improve in the future. A central argument for this is that more and more countries or regions have or plan to supplement the police recorded accidents with hospital recorded traffic accidents.

– The problem of too “few” accidents to make a reliable black spot identification is only present in the most safe countries that have identified and improved black spots for decades, while it can be argued that there still are “plenty” of accidents in the less safe countries and regions to make a reliable black spot identification possible in spite of low level of reporting in the official accident databases.

– The not accident based methods will typically be based on some kind of observation. This causes an additional point of criticism. Identification based on inspection and registration for the complete given road network will mean that the identification stage will be very comprehensive, which is not the philosophy and intention of BSM (Thorson 1970, Hauer et al. 2002).

Among both the model and the not model based identifications principles you find the so called specific identification principles.

The advantage of these principles is that the identification is based solely on site-specific accidents through specific accident themes or types or accidents associated with road related risk factors whereby all interference from not site specific accidents is removed already in the identification stage. This means that the link between the different stages in BSM will be improved, because the analysis in a way already is started during the identification stage. It can be argued that this will give a more effective traffic safety work compared to the normal division of the work in different more or less independent stages (Sayed et al. 1995, 1997, Kononov 2002).

However, these accident specific methods are not recommended. The reasons for that are the following:

- A significantly high number of accidents at a location compared to similar locations must indicate that there are local risk factors and it is thus unnecessary to limit the identification to road related accidents to find sites with road related traffic safety problems (Thorson 1970).
- It can turn out to be a problem to limit the accident data, which already is limited in many countries due to incomplete accident reporting
- An accident specific identification will demand a relatively comprehensive identification stage. For instance it is necessary to analyse what accidents have road related risk factors. However, the normal procedure and philosophy for BSM is that the identification should demand relatively little resources (Thorson 1970, Hauer et al. 2002).
- Focus on certain themes and accident types can result in the failure to identify other traffic safety problems on the concerned sites.

In addition to the principles listed in figure 3.3 so called GIS based identification methods (geographic information system) are more and more seen, see for example Højgaard et al. (2006). In general, the principle is that the concerned area is divided into more or less squares, and the number of accidents in every square is counted. Black spots are then defined as the squares with most accidents.

These methods have not been evaluated in this report. However, the use of these methods in BSM can be questioned from a more theoretical point of view. The general problem is that accidents are attached to areas, not intersections and road sections. This makes it at first sight impossible to take traffic and road design into account in the identification of black spots. Thus, the principle is not recommended.

3.3.2 State-of-the-art approach

Black spots should be identified in terms of the expected number of accidents estimated by using the empirical Bayes method.

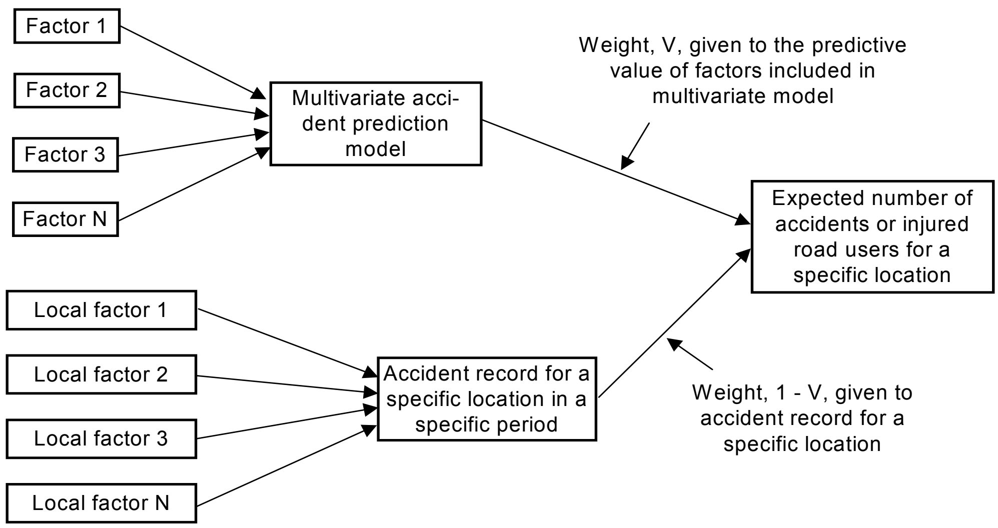

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Figure 3.4. Illustration of the empirical Bayes method, where information about the normal and registered number of accidents is combined for estimation the local expected number of accident for a specific location.

In the empirical Bayed method, the expected number of accidents on a specific location is estimated by weighting the registered number of accidents on the location and the general expected number of accidents for similar sites estimated by accident prediction models. This method is illustrated in figure 3.4 and in the following formula:

$$E(\lambda/r) = \alpha \cdot \lambda + (1 - \alpha) \cdot r, \text{ where}$$

$$\alpha = \frac{1}{1 + \lambda/k} \text{ (weight)}$$

$E(\lambda/r)$: The local expected number of accidents on a specific location

λ: The general expected number of accidents estimated by accident models

r: The registered number of accidents on the location

k: The inverse value of the overdispersion parameter

Table 3.4. A numerical example to illustrate the use of the empirical Bayes method. The example is taken from Elvik (2004, 2007).

The normal number of accidents for a location during a period of 8 years has been estimated by an accident model to be 3,73. The overdispersion parameter for the model is 0,3345. 7 accidents were registered.	λ = 3,73 r = 7 k = 1/0,3345 = 2,99
Based on these numbers the local expected number of accidents can be estimated as shown to the right.	α = 1/(1+3,73/2,99) = 0,445
Based on the calculation the regression-to-the-mean expected to occur in a subsequent 8-year period can also be estimated to 20,9 %.	E(λ/r) = 0,444 · 3,73 + (1-0,445) · 7 = 5,54 Regression to the mean = (7-5,54)/7 = 0,209
The different between E(λ/r) and λ can be interpreted as an effect of local risk factors	Effect of local risk factors = 5,54-3,73 = 1,81

Table 3.4 illustrates the use of the formula by a numerical example.

Several research projects have documented that black spots are most reliably identified by applying the empirical Bayes technique. It has both been documented theoretically (Overgaard Madsen 2005a), empirically (Persaud 1990, Persaud et al. 1997, 1999, Elvik 2007, 2008a) and by simulation (Vistisen 2002, Cheng and Washington 2005). In the following, the project by Elvik (2007, 2008a) is summarized.

Five techniques for identifying black spots were compared, using data referring to national roads in Norway, which have been divided into road sections of 1 kilometre. The number of sections included in the study was 19,623.

Data for two periods of four years were used. These data covered the period from 1997 to 2004. Black spots were identified on the basis of data referring to the first four years. To assess whether black spots were true or false positives, data referring to the second four year period were used. The idea was that true positives will persist in having a bad safety record, whereas false positives will regress towards a more normal safety record. There will also be some false negatives, i.e. sites not detected in first four years that are detected in the second four years.

An accident model was developed based on first four years. The model included the following explanatory variables: AADT, speed limit, number of lanes, number of intersections per kilometre of road and a dummy for trunk roads.

The following five techniques for identifying black spots were compared:

1. *Upper tail accident count*: Sites whose recorded number of accidents belonged to the upper 2.5% of the distribution during the first four years were identified as black spots. Sites that continued to belong to the upper 2.5% in the second period were classified as correct positives. Sites that dropped out of the list were classified as false positives; new sites entering the list were classified as false negatives.
2. *A critical accident rate*: Accident rate was defined as the number of injury accidents per million vehicle kilometres. Sites that had the 2.5% highest values for the accident rate were classified as black spots. Sites that continued to belong to the top 2.5% in the second period were classified as correct positives. Sites whose accident rate dropped below the top 2.5% were classified as false positives. Sites that did not belong to the top 2.5% in the first four years, but did so in the second four years were classified as false negatives.
3. *A critical rate and number of accidents:* Sites that recorded a number of accidents greater than the upper 2.5% values in the population of sites, and had a higher than average accident rate were classified as black spots. Sites that during the second four year period continued to satisfy both criteria were classified as correct positives. Sites that in the second four year period failed to satisfy one or both criteria were classified as false positives. Sites that did not satisfy the criteria in the first four years, but did so in the second four years, were classified as false negatives.
4. *Upper 2.5% EB-criterion*: For each site, the EB-estimate of the expected number of accidents for that site was developed, based on four years of data combined with an estimate of the normal number of accidents based

on an accident prediction model. Sites with the 2.5% highest estimates were classified as black spots. If the EB-estimate for these sites in the second four year period remained in the upper 2.5%, the sites were classified as correct positives. Sites that dropped out of the upper 2.5% were classified as false positives; new sites that entered the list were classified as false negatives.

5. *The EB-dispersion criterion*: For each site, an EB-estimate of safety was developed. The recorded number of accidents, for sites that had a higher recorded number of accidents than the number predicted according to the model, was decomposed into contributions from randomness, general risk factors and local risk factors. Sites were sorted by the contribution from local factors; sites at the top 2.5% were classified as black spots, provided the recorded number of accidents was 4 or more. Sites that remained in the upper 2.5% in the second period were classified as correct positives. Sites that dropped out were treated as false positives; new sites entering were treated as false negatives.

The procedure was repeated using the upper 1 % and 5 % as critical values. To evaluate the diagnostic performance of these techniques, the following two criteria were used:

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

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

Table 3.5. Comparison of five techniques for identifying black spots based on Norwegian data (Elvik 2007, 2008a).

Identification criterion	**Correct negatives**	**Correct positives**	**False negatives**	**False positives**	**Sensitivity (1)**	**Specificity (2)**	**1+2**
			Top 1 % of distribution				
Accident count	19272	134	109	108	0.551	0.994	1.545
Accident rate	19232	16	188	187	0.078	0.990	1.068
Accident rate and count	19340	86	94	103	0.478	0.995	1.473
EB-estimate of accidents	19378	130	53	62	0.710	0.997	1.707
EB dispersion criterion	19311	62	121	129	0.339	0.993	1.332
			Top 2.5 % of distribution				
Accident count	18788	285	262	288	0.521	0.985	1.506
Accident rate	18726	53	418	426	0.113	0.978	1.091
Accident rate and count	18928	186	236	273	0.441	0.986	1.427
EB-estimate of accidents	18981	338	152	152	0.690	0.992	1.682
EB dispersion criterion	19070	105	195	253	0.350	0.987	1.337
			Top 5 % of distribution				
Accident count	18065	464	526	568	0.469	0.970	1.439
Accident rate	17838	144	805	836	0.152	0.955	1.107
Accident rate and count	18308	307	474	534	0.393	0.972	1.365
EB-estimate of accidents	18429	692	235	267	0.746	0.986	1.732
EB dispersion criterion	18989	136	219	279	0.383	0.986	1.369

The total number of positives equals the number of correct positives plus the number of false negatives. The total number of negatives equals the number of correct negatives plus the number of false positives.

To compare the performance of the different techniques, the values of sensitivity and specificity are added, since a good diagnostic test should score high on both criteria. Table 3.5 presents the results of the analysis. The empirical Bayes technique is found to perform best at all three levels of stringency, and hence it provides a more reliable identification of black spots than traditionally used criteria, like the recorded number of accidents, the accident rate or the combination of accident rate and number.

The advantage of adopting the empirical Bayes technique for identifying black spots is that the problem of false positives and false negatives is minimised. While no technique can perfectly identify black spots, the empirical Bayes technique comes closest.

3.3.3 Best practice guidelines

In the review of BSM in different countries in chapter 3.1.3, it is documented that several countries are far from the state-of-the-art approach for identifying black spots. It is utopia to think that the state-of-the-art approach can be implemented immediately in all these countries because it will demand a lot of data collection and inter-connection as well as resources for development of a "national" empirical Bayes method.

Nevertheless, there are ways to get closer to the state-of-the-art approach even if the resources and the data quality and quantity are limited. Some recommendations are given below.

The recommendations for best practice guidelines are divided into so called second respectively third best methods ranked in relation to the state-of-the-art approach, which is considered as the best method. What methods that can be considered relevant for each country or road administration depend on resources, data and current stage for the BSM.

Second best method: Traditional model based method

Model based methods are the best to make reliable identification of sites with local risk factors related to road design and traffic control, because systematic variation and partially random fluctuation are taken into consideration.

The second best method after the state-of-the-art approach is thus a simpler and traditional model based method. Table 3.6 summarizes characteristics of the traditional model based method in comparison with the state-of-the-art approach.

The main difference between the traditional model based method and the empirical Bayes method is that the recorded number of accidents and not the local expected number is used and compared with the general expected number of accidents. This means that the general road design and traffic (systematic variation) are taken into account, so sites with local risk factors related to road design and traffic control are identified, which match the overall philosophy for BSM. However, the stochastic nature of the accidents is only partly taken into account. Compared with the state-of-the-art approach there is thus an increased risk of making errors of the type false positive and false negative in the identification.

To make a traditional model based identification the same data about accidents, road design and traffic volume are needed, but the resources for development and use of the method are apparently smaller, because the calculations are less comprehensive and advanced.

The traditional model based method is combined with the use of not model based method to ensure a minimum of accidents on the identified locations. How many accidents there should be on the location depend on general traffic safety level and resources for BSM.

Table 3.6. Characteristics of the traditional model based method in comparison with the state-of-the-art approach with regard to identification principle, quality, demand for data and resources for development and implementation.

Principle	– Ratio or absolute difference between the registered and general expected number of accidents instead of ratio or absolute difference between the local expected and general expected number of accidents
Quality	– Systematic variation in the number of accidents due to general road design and traffic volume are taken into account – Random fluctuation due to the stochastic nature of accidents is only partly taken into account – Sites with local risk factors related to road design and traffic control are identified (if the problem of random fluctuation are ignored)
Data	– Same data demands as state-of-the-art approach (Comprehensive and connected accident, road and traffic data)
Resources	– Probably less resources (time, money, personnel and professional expertise) for development, implementation and application than the state-of-the-art approach

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Third best method: Category based method

The simple version and a precursor for the model based identification method is the category based method and this is therefore classified as the third best method. Some characteristics for the category based method are summarized in table 3.7.

The main difference between the model and category based method is that the registered number of accidents is compared to the general expected respectively the average number of accidents for similar locations. The average number of accidents is the average for a traffic volume interval, while the general expected number is the number for a specific traffic volume.

This means that the general road design and traffic (systematic variation) are taken into account, while the stochastic nature of the accidents only can be taken very partly into account by the use of longer identification periods.

Less precise data about the traffic volume are needed, because it is not necessary to know the exact traffic volume as the volume is divided into different intervals. However, information about the road design is still necessary, because it is used to divide the road network into different road categories.

A last very important point is that fewer resources, especially for developing the method, are needed because no regression analyses have to be made. This also means that more people can make the analysis and understand the results.

Table 3.7. Characteristics of category based method in comparison with state-of-the-art approach with regard to identification principle, quality, demand for data and resources for development and implementation.

Principle	– Ratio or absolute difference between the registered and average number of accidents instead of ratio or absolute difference between the local expected and general expected number of accidents
Quality	– Systematic variation in the number of accidents due to general road design and traffic volume are taken into account – Random fluctuation due to the stochastic nature of accidents is not taken into account – Sites with local risk factors related to road design and traffic control are identified (if the problem of random fluctuation is ignored)
Data	– Less data demands with regard to traffic volume and the same data demands with regard to road data as the state-of-the-art approach
Resources	– Less resources (time, money, personnel and professional expertise) for development, implementation and application than the state-of-the-art approach

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Methods that are not model or category based should not be used, because neither systematic variation nor random fluctuations are taken adequately into account. However, in a few cases, it can be necessary to use these methods in a transition period until necessary road and traffic data are collected and connected with the accident data permitting as a minimum the development and use of the category based identification method. In this situation, the frequency-rate method is to prefer.

3.3.4 Implementation steps

This section describes how a more or less advanced model based method for identification could be implemented. Elvik (2007) and Overgaard Madsen (2005a) have in great detail has described some general recommendations for making an accident model respectively described how accident prediction models in practice should be made. This is summarized in the following.

The estimation of an accident model could be summarized in the following steps:

1. Objective and field of application
2. Dependent and independent variables
3. Collection of data
4. Choice of method for estimation
5. Regression analysis
6. Goodness of fit
7. Empirical Bayes estimation

The steps are explained in the following. Note that the steps are described as a linear process, but in practice, the process will have a more iterative nature.

Step 1. Objective and field of application

The questions in the first step are what the accident model should be used for, and if one should aim for a model with a high coefficient of determination or a model with good prediction ability. At the same time the level of ambition should be adjusted to the given economic resources for the work. In other words, it should be decided if the ambition is the state-of-the-art approach or the best practice guidelines.

Accident models are primarily used to:

1. Identify black spots or other hazardous road locations
2. Make better before-after studies (Hauer 1997)
3. Assess what general road layout is the safest
4. Assess reconstruction of roads or new traffic facilities before implemented

In this project focus is primarily on the first point and secondarily the second point. If the model is to be used for the last three points it is desirable that as many as possible of the possible independent accident variables are included in the model. On the other hand, if the model primarily is to be used for black spot identification according to the state-of-the-art approach it is only the general and not the local factors with significant influence on the number of accidents that should be included. This makes a less resource-demanding model development possible.

Step 2. Dependent and independent variables

Step 2 comprises identification and selection of possible dependent and independent variables in the model.

The dependent variable is accidents or injured road users, or a subset of these. Different possibilities are listed in the following:

Accidents

- All accidents
- Fatal accidents
- Accidents with seriously injured
- Accidents with slightly injured
- Accidents with property damage
- Combination as for example fatal accidents and accidents with seriously injured

Injured road users

- All injured
- Killed
- Seriously injured
- Slightly injured
- Combination as for example killed and seriously injured

What should be used depends on the level of traffic safety, policy for the future number of accidents, accident data and the desired reliability of the model. Normally accidents are used as the dependent variable. This is preferable, because the number of injured road users can be a result of parameters that have nothing to do with the road design such as number of passengers, deficient use of seat belts or helmets, characteristics of involved persons such as age and shape and characteristics of involved vehicles. Therefore, the use of injured road users as basis for the identification can give misleading results.

The independent variables are data about traffic and road layout that have significant influence on the number of accidents. In the selection of variables, other accident models and evaluation studies can be used as inspiration. Normally it is to be recommended to include as many possible variables as possible, because variables with no significant influence will be excluded in the modelling. However, it should be noted that these tests of different possible variable make the process more expensive. The possible independent variables can be divided into the following main groups:

– Traffic volume and composition
– Traffic flow
– The standard of the road
– Road layout
– Road environment
– Behavioural characteristics of the road users

Table 3.8 shows an example on what independent and dependent variables that are used in a Norwegian and a Danish accident model for the main roads.

Table 3.8. Independent and dependent variables in Norwegian and Danish accident models for the main roads (Ragnøy et al. 2002, Overgaard Madsen 2005).

	Norway **Road sections**	**Denmark** **Road sections**	**Denmark** **Intersections**
Dependent variables	– Fatally injured road users – Critically injured road users – Seriously injured road users – Slightly injured road users	– All accidents – Injury accidents	– All accidents – Injury accidents
Independent variables	– AADT – Speed limit – Type of road – Number of lanes – Number of junctions per km – Status of road	– AADT – Road buildings – Type of road – Number of lanes – Present of bicycle lane or side strips	– AADT – Type of intersection – Traffic signals – Channelization – Road buildings

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Step 3. Collection of data

In the third step data about accidents, traffic volume, roads and the surrounding environment have to be collected. It is data for the chosen possible independent and dependent variables in the previous step that as a minimum should be collected.

Accident data are normally recorded by the police, while traffic and road data are recorded by the public roads administration.

All the data have to be unambiguously located on the road network by use of for example stationing along all roads in the road network as described in chapter 3.2.3. In addition, the data have to be immediately interoperable with each other so it is possible to make an analysis of the correlation between the different data.

The length of the accident period used for the accident prediction modelling is normally between three and five years. This period is recommended, as it will better balance on the one hand a reliable modelling based on as much accident data as possible, and on the other hand, an actual one that is not influenced by general tendencies and specific changes at the sites included in the modelling. Locations that have been changed in the last two to three years should not be included in the modelling.

Step 4. Method for estimation

Before it is possible to make the modelling itself, the method for estimation has to be chosen. The first question is whether the model should be estimated as a combined category and regression analysis or a multivariate regression analysis.

The second question is what assumption should be made about the distribution of the residual terms. The residual term of a model is the part of systematic variation in accident counts, plus random variation, which is not explained by the model.

If a model explains all the systematic variation in accident counts there is in a data set, the residuals will by definition contain random variation only and can be specified as Poisson distributed. Usually, however, a model will not be able to explain all systematic variation in accident counts. The residuals will then contain some over-dispersion, which can usually be adequately described by the negative binomial distribution. Other probability distributions have also been fitted to accident data, but the Poisson and negative binomial are the most commonly used distributions.

Step 5. Regression analysis

Step 5 is the step where the model itself is fitted according to preliminary work in the previous four steps. It has to be determined which of the possible independent variables chosen in the second step that have significant influence on the number of accidents and therefore should be included in the model.

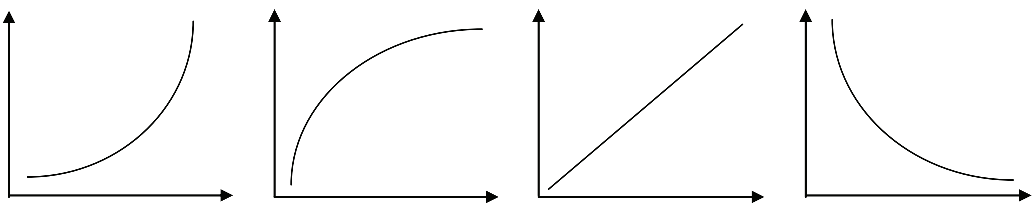

Figure 3.5. Functional forms consistent with a power model or an exponential model (Elvik 2007).

The functional relationship between the number of accidents and the independent, explanatory variables with significant influence also has to be examined. In the standard formulation of accident prediction models, a power function is applied to describe the effects of exposure, and an exponential function applied to describe the effects of risk factors. These functional relationships can both take on many shapes, including all those shown in figure 3.5.

Finally the estimation of relevant regression coefficients can be done.

If one decides to do a multivariate regression analyse, the model estimation can be done either as a forward or as a backward elimination.

In the forward elimination, you start the model estimation with including the variable that is assumed to have the largest significant influence on the number of accidents and examine if it has a significant influence. Then you take the variable with the assumed second largest significant influence, load it into the model, and examine if it has significant influence. This is done for all the variables and variables with significant influence are included in the model, and variable with no significant influence are excluded.

In the backward elimination the procedure is just the opposite. You start the model estimation by including all the chosen variables. Then you exclude the variable with the least significant influence and the model is estimated again. This procedure is continued until the model solely consists of variables that have significant influence on the number of accidents. The basic form of nearly all modern accident prediction models made as multivariate regression analyse is:

$$E(\lambda) = \alpha \cdot Q^{\beta} \cdot e^{\sum \lambda_i \cdot x_i}$$, where

$E(\lambda)$: The estimated expected number of accidents

Q: Traffic volume

X_i: Variables denoting risk factors

α, β, γ_i: regression coefficients

If a combined category and regression analysis is chosen, the first step is to divide the variables in possible category and regression variables. Category variable are normally discrete variables such as standard of the road, road layout and road environment, while regression variables are continuous variables like traffic volume. This means that the road network is divided into different categories and for each category a regression analysis is made with the traffic volume as regression variable. This means that you have a number of accident models. These models normally have the following basic form:

$$E(\lambda) = \alpha_i \cdot Q^{\beta_i}$$, where

$E(\lambda)$: The estimated expected number of accidents

Q: Traffic volume

α_i, β_i: regression coefficients for each category

Step 6. Goodness of fit

In step 6, an evaluation of the goodness of fit of the developed accident prediction model should be made. This refers to the models ability to explain and estimate the systematic variation in the accident counts. Several measures have been proposed for that purpose. Some of them are:

- θ: The dispersion factor
- R_p^2: The Poisson adjusted coefficient of determination
- R_W^2: The weighted coefficient of determination
- R_{FT}^2: The Freeman-Tukey coefficient of determination
- R_E^2: The Elvik index (Fridstrøm et al. 1995)

As an example the first measure, θ, is calculated as the reciprocal value of the overdispersion parameter. If θ is close to zero, it can be concluded that the model captures the systematic variation and therefore provides a good estimate of the expected number of accidents.

Step 7. Empirical Bayes estimation

To get an estimate of the local expected number of accidents it is necessary to combine the model estimated number of accidents with the registered number of accidents on each location in the road network by use of the empirical Bayes approach described in chapter 3.3.2.

3.4 Identification criteria

In the previous section, it was recommended that black spots are identified by a more or less advanced model based method. Model based identification methods allow for the use of different identification criteria. What identification criteria should be used according to the recommended state-of-the-art approach and best practice identification method is summarized in the following. Finally, it is explained what should be done to implement these recommendations.

3.4.1 State-of-the-art approach

The description of the state-of-the-art approach is divided into recommendations about the expected number of accidents, the registered number of accidents and exclusion of severity in the identification criteria.

Expected number of accidents

Black spots should be identified as sites that have a higher expected number of accidents than the normal expected number on similar roadway elements due to specifically local risk factors.

In practice, however, precise estimation of the contribution of local risk factors to accidents at black spots may not be possible. Therefore, alternative minimum criteria for the number of accidents should be investigated in terms of sensitivity and specificity and an optimal criterion should, if possible, be chosen.

Why the recorded number of accidents should not be used and how the optimal criterion should be chosen is discussed below by means of an example (Elvik 2007).

Assume that black spots are to be identified from a population of 1,000 sites. Table 3.9 lists this population, stratified into homogeneous groups with respect to the expected number of accidents. In practice, the expected number of accidents in a population of sites is a continuous variable, that cannot readily be stratified into homogeneous groups as shown in table 3.9. The stratification is used for expository purposes only.

The first column shows the count of accidents. The distribution of sites by the number of accidents in each group was generated by assuming that accidents are Poisson distributed. This is equivalent to assuming that a perfect accident prediction model has been developed, which is able to explain all systematic variation in the number of accidents and discriminate perfectly between the groups formed in table 3.9. In practice, of course, a perfect model is never developed; in the following, it is assumed that only the column to the right is known. The groups are not known. They serve only to model the accident generating process if that process were perfectly known.

Table 3.9. A population of 1,000 sites stratified according to the expected number of accidents (Elvik 2007).

	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

Sites whose expected number of accidents is four are defined as black spots. This means that there are 50 black spots and that the accidents at these represent 25% of the total number of accidents in the population.

How can we best identify the black spots in this population? By assumption, the road safety manager knows only the rightmost column in table 3.9, not the data for each of the groups. In other words, the recorded number of accidents and its variation between sites is known; the expected number of accidents for each site is unknown. Hence, to identify the black spots, the only option is to rely on the recorded number of accidents. It seems logical to identify sites that had four or more recorded accidents as black spots.

By this criterion, 66 sites will be identified as black spots. Among these sites, however, only 28 will be true black spots, meaning their expected number of accidents is four. These are the 28 sites that recorded at least four accidents whose expected number of accidents is also at least four. These sites are found in the column for sites with an expected number of accidents equal to four. The remaining 38 sites will be false positives. These sites consist of sites that recorded four or more accidents, but have an expected number of accidents less than 4. We may now define four categories of sites:

1. *Correct positives:* Sites at which the expected number of accidents exceeds the critical value selected and the recorded number of accidents exceeds the same critical value.
2. *False positives:* Sites at which the expected number of accidents does not exceed the critical value selected, but the recorded number of accidents does exceed this value as a result of random variation.
3. *Correct negatives:* Sites at which both the expected and recorded number of accidents are lower than the critical value selected.

4. *False negatives:* Sites at which the expected number of accidents exceeds the critical value selected, but the recorded number of accidents does not, due to random variation.

Table 3.10. Number of correct negatives, false negatives, correct positives and false positives on condition that sites whose expected number of accident is four are defined as a black spot (Elvik 2007).

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

Table 3.10 shows the number of sites in these groups as a function of the recorded number of accidents used to identify black spots.

For example, if all sites that have recorded at least one accident are included, 364 sites will be identified. The great majority of these, 315 sites, will be false positives. There will be 49 correct positives and 1 false negative. Thus, even if the criterion is set as low as it could possibly there will still be one black spot that is not detected.

If more stringent critical values are adopted, fewer sites will satisfy them. A growing proportion of the sites identified will be correct positives, but this is accomplished at the cost of a growing number of false negatives. At nine accidents, only a single site is identified, but 49 sites go undetected.

It can be seen that no criterion for identifying black spots is perfect. The reason is very simple. We cannot observe the expected number of accidents. We can only observe the recorded number of accidents, which is always partly the outcome of chance, partly the outcome of very many factors that systematically influence the expected number of accidents.

The performance of the various criterion values can be assessed quantitatively in terms of sensitivity and specificity explained in chapter 3.3.2.

With reference to table 3.10, the sensitivity of using four accidents as the diagnostic criterion is 28/50 = 0.56. The specificity of this criterion is 912/950 = 0.96. The performance of different values for the critical number of accidents used to identify a black spot can now be assessed in terms of a receiver operating characteristic curve (ROC-curve). Such a curve is shown in figure 3.6.

The false positive rate is plotted along the abscissa. This is equal to one minus specificity. The true positive rate (sensitivity) is plotted on the ordinate. If the diagnostic test discriminates well, the ROC-curve will rise steeply, close to the ordinate and flatten out near the top of the diagram. If the diagnostic test is uninformative the ROC-curve will follow the diagonal line indicated in figure 3.6.

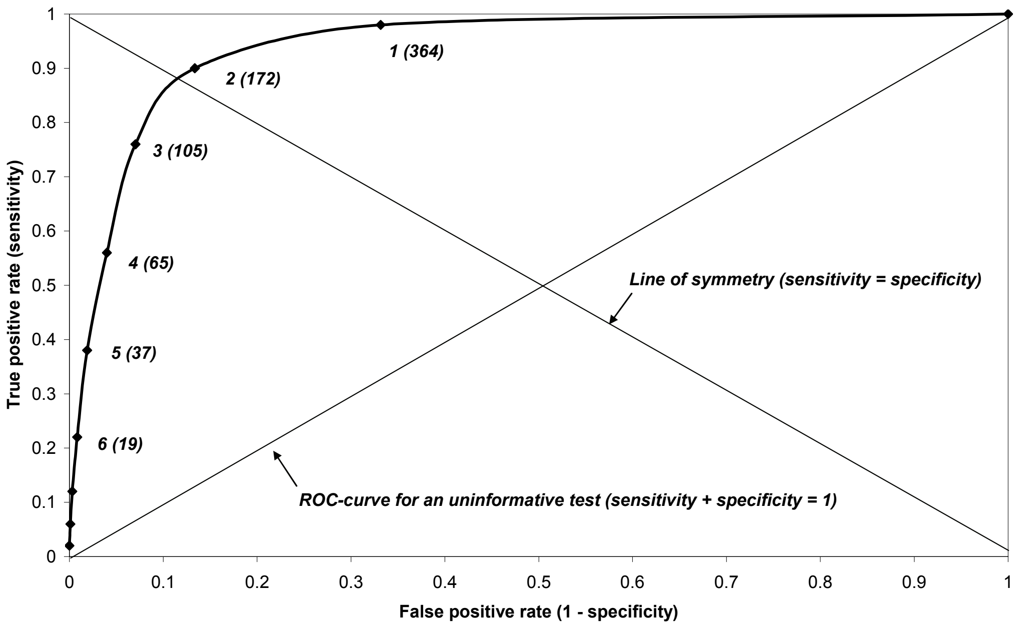

Figure 3.6. ROC-curve for detecting black spots based on data from table 3.10 (Elvik 2007).

It is desirable to minimise the false positive rate and to maximise the true positive rate. This involves a trade-off; one may diminish the false positive rate by accepting a lower true positive rate, and vice versa. The optimal criterion is the one that maximises the sum of sensitivity and specificity. For figure 3.6, this is to treat all sites with two or more accidents as potential black spots. This is marginally better than using three accidents as the criterion.

In practice, the criterion defining a black spot is rarely, if ever, based on an evaluation of the diagnostic performance of the criterion. Ideally speaking, an optimal criterion of deviance ought to be chosen. On the other hand, practical considerations may prevent this. In the example above, if all sites with two or more accidents are treated as black spots, 172 sites would be identified, of which 127 would be false positives. This would create a considerable amount of work in performing accident analysis for the purpose of diagnosing problems at each site and, again ideally speaking, reliably identify the true and false black spots. Thus, the choice of a criterion for identifying black spots cannot be based on a statistical criterion only. No statistical criterion can reliably identify only correct black spots, and include all of them, as the criterion would always be applied to a population of sites containing a mixture of random and systematic variation in the number of accidents. Indeed, the very idea of selecting black spots from a population of sites containing random variation only is a contradiction in terms, as a true black spot should always be defined as having a higher expected number of accidents than other, similar sites. In a completely homogeneous population, by definition no such sites would exist. One must therefore always identify black spots in a heterogeneous population that contains unexplained systematic variation in accident counts, with random variation on top of this.

This means that any criterion will be imperfect: Sites identified as black spots will always contain a mixture of correct positives and false positives. Besides, there will always be a number of false negatives. The number of sites that are true or false black spots will almost never be known.

Registered number of accidents

The above points imply that black spots cannot be reliably identified in terms of a critical count of accidents. For the purposes of accident analysis, it is nevertheless wise to identify only sites that have a certain minimum number of accidents as black spots.

Severity

More and more European countries and road administrations focus on the most severe accidents in their road safety policies (European Commission 2007).

However, accident severity should not be a part of the identification itself, because black spots often have to "few" accidents to make a meaningful consideration of the accident severity in the identification.

Instead, severity should be included in a preliminary analysis of the accidents at black spots and sites that have a high mean cost per accident should be ranked high on a list for more detailed engineering analysis.

The cost of the accidents should be estimated, preferably by relying on a model that allows estimation of the expected number of accidents at each level of severity. In case such a model is not be applicable, the cost of accidents should be calculated on the basis of the recorded number of accidents.

3.4.2 Best practice guidelines

In principle, many different identification criteria exist (Sørensen 2006), but within the recommended model based identification method primarily two different types of criteria are relevant. These are the so called ratio criterion and absolute difference criterion also named savings potential.

By use of the ratio criterion black spots are identified as sites with the highest ratio between the registered or local expected number of accidents and the general expected, average, minimal or target number of accidents. The identification is thus done by the following generalized formula:

$$\text{Ratio} = \frac{\text{Registered or local expected number of accidents}}{\text{General expected, average, minimal or target number of accidents}}$$

In the second criterion, black spots are identified as sites with the highest absolute difference (not ratio) between the registered or local expected number of accidents and the general expected, average, minimal or target number of accidents. The identification is thus done by the following generalized formula:

Absolute difference = (Registered or expected number of accidents) – (general expected, average, minimal or target number of accidents)

What parameters one should use in the two criteria depend of the quality of the accident model used. In simple models as recommended as best practice guidelines it is the registered number of accidents which is compared to the general expected number of accidents (traditional model based identification) or the average number of accidents (category based identification). In the empirical Bayes identification method, it is the local expected number of accidents, which is compared with the general expected number of accidents.

Besides comparison with the expected number of accidents a comparison can be made with the so called minimal number of accidents, with is the number of accidents on different locations with best practice design. The logic of this is that a minimal number of accidents are to aim at, and therefore it also has to be the basis for the identification. Alternatively, a target number of accidents for different types of location can be used. However, neither a minimal nor a target number are normally used.

Absolute difference rather than ratio

It is recommended that the absolute difference criterion is used in relation with the traditional model based and category based method for identification of black spots.

The argument for this is that the use of this criterion ensures focus on locations, which have the largest saving potential in the number of accidents if the number after improvement of the identified locations is reduced to the general expected, average or minimal number of accidents for similar types of locations. Assuming that locations identified by this criterion not being more expensive to treat than other locations this criterion will also ensure the best cost-effectiveness.

It is not possible for the more simple model based identification methods to control for random fluctuations in the same manner as in the empirical Bayes method. Therefore, the ratio criterion is more relevant for the modern model based identification methods, while the absolute difference criterion is considered as the most relevant for the more simple methods.

However, this means that there is a risk of errors of the type false positive and false negative in the identification. To make up for that it is very important that the analysis stage evaluate if the identified locations are true black spots or not. This will eliminate the problem of false positives, but not the problem of false negatives.

As stated in the description of the state-of-the-art approach the absolute difference criterion can, for the purpose of accident analysis, be supplemented by a criterion regarding the registered number of accidents at the identified sites.

Finally, it should be noted that absolute difference or savings potential is not necessarily the same as the actual number saved if proposed improvements are implemented. The savings will often be larger because the sites after improvement typically will be better than the average or what is generally expected for similar sites.

Specific identification criterion

Given that the absolute difference criterion is used as identification criterion, it has to be considered how big the absolute difference should be, before a location is identified as a black spot.

The specific criterion to be used depends on general policy for the future number of accidents and what is regarded as an acceptable accident level, staff and economic resources, accident data and desired reliability of the identification (O'Flaherty 1967, Thorson 1970, Joly et al. 1992). This means that you cannot apply one common criterion, which has validity for all the countries and road administrations in Europe. However, it is possible to conduct some more general discussions and recommendations.

The criterion for identification can be divided into the following two principles (Sørensen 2006):

- A predefined number that the savings potential has to exceed
- A certain percentage of the road network with the largest savings potential

What principle should be used depends on how the BSM is organized and divided between different road administrations.

A certain percentage of the road network with the largest savings potential can be used at national and large regional black spot identifications as is for example done in Norway in the NSM (Ragnøy et al. 2002).

If the black spot identification is done independently for several smaller regions, the predefined number is recommended. The reasons are (Sørensen 2006):

- If the same percentage is used in all regions you risk that the most safe regions mostly identify (and maybe treat) false black spots.
- The definition of black spots will vary from region to region. This means that it will be complicated to get a common understanding for the work.

Severity

For the state-of-the-art approach for BSM, it is concluded that accident severity should not be a part of the identification itself. It is simpler to exclude accident severity in the identification than include it, so this recommendation is retained for the best practice guidelines for BSM.

It is however also recommended that accident severity should be included in a preliminary analysis of the accidents at black spots for ranking them for more detailed engineering analysis. How to include accident severity is discussed in the section dealing with NSM. It is recommended that severity be included by means of a weighting principle where fatal accidents and accidents with seriously injuries are weighted more than accidents with minor injuries and accidents with only property damage, if recorded. See chapter 4.3.2 for more details about how to weight accidents.

3.4.3 Implementation steps

It is a prior assumption that a more or less advanced model based method for identification of black spots has been develop and implemented as described in chapter 3.3.4. This means that the registered, the normal or the average and maybe the local expected number are known, and that different relations like the ratio or absolute different can be calculated for all locations in the actual road network.

The next step is to assess and chose what concrete identification criterion should be used. This will vary from country to country. Therefore it is impossible to recommend a specify identification criterion that is applicable for all countries. It has to be assessed and chosen more or less isolated for each country or region.

The following points influence and can be used in the assessment:

- General policy for the future number of accidents and current accident level
- General safety problems and focus in the traffic safety work
- The quality and quantity of the accident data
- Organisation of BSM. Is it centralized, decentralized or both
- Staff and economic resources to analyse and treat black spots
- Desired reliability of the identification with regard to minimize the number of false positive or minimize the number of false negative
- Desired minimum number of accidents for the accident analysis
- Quality of the following analysis stage and the ability of these analyses to identify false black spots, see chapter 2.3

Severity

It is recommended to include accident severity in a preliminary analysis of the accidents at black spots for ranking them for more detailed engineering analysis. This should be done by use of a weighting principle where fatal accidents and accidents with seriously injuries are weighted more than accidents with minor injuries and accidents with only property damage. The weight should be based on the mean cost per accident.

This means that it is necessary to have information about the mean costs for traffic accidents or injured road users. This information is probably available in most countries. If it is not the case, these costs have to be estimated. However, this is very complicated and will not be treated in this report.

It also means that models that allow estimation of the expected number of accidents at each level of severity should be made. The development of such models follows the same steps as described for estimation of a model for all accidents.

3.5 Accident analysis

Research, development and testing of new and better methods in BSM have primarily been focusing on the identification stage and to a limited extent also the evaluation stage. With regard to the identification stage, this means that methods have continuously been developed, improved, compared and evaluated. Therefore, we know a lot about the advantages and disadvantages of the different methods and what method is the best, second best and third best.

It is a different case with the analysis stage. For this stage research, development and testing of new and better methods has only been done to a minor extent. Thus, it is more or less the same method that has been used for the last over 40 years, and the work is to a large extent based on tradition, procedures and experience in each individual road authority. This means that further research, development and testing is needed to be able to distinguish better between false positives and true positives and secondly to be better able to identify accident and injury risk (Sayed et al. 1995, Hauer 1996, Sørensen 2006, 2007a, Elvik 2006, 2007).

However, a new and improved method has been developed by Elvik (2004, 2006, 2007). This is in the following described as the state-of-the-art approach for accident analysis of presumed black spots. Afterwards some best practice guidelines are given. Finally, it is explained what should be done to implement these recommendations.

3.5.1 State-of-the-art approach

In the analysis stage, the designated and presumed black spots have to be analyzed in order to firstly ascertain whether they are true or false black spots, and, if so, secondly assess why they have become black.

With reference to the first objective, it has to be noted that it empirically can be questioned if all people working with BSM are conscious of this objective. This means that in some cases false black spots are treated, which results in an ineffective use of resources (Elvik 2006, Sørensen 2007a). The objective is for example not mentioned in some central international textbooks and manuals (Khisty 1990, Ogden 1996 and PIARC Technical Committee on Road Safety 2003) nor some more national manuals (Harwood et al. 2002a, Statens vegvesen 2006 and Højgaard et al. 2006). However, the objective is described in some few textbooks (Thorson 1970, O'Flaherty 1997 and Elvik 2004).

This objective is very important especially – as described in chapter 2.3 – when best practice guidelines and not the state-of-the-art approach is used in the identification stage. It is therefore recommended that the question about true and false is raised for every location analysed – also when the best practice guidelines and not the state-of-the-art approach are used in the analysis stage. You can say that it is better to make the assessment by use of the second or third best method than completely omit to do it.

As far as the second objective is concerned, it should be clarified that it concerns both identification of accident factors (why the accident happened) and injury factors (why the accident became serious). The last part is especially central if the road safety policy focuses on the most serious accidents.

Table 3.11. The Haddon-Matrix, which specifies nine different approaches to traffic safety work (Haddon 1970).

	Road user	Vehicle	Road	Method
Pre-crash phase	1a	1b	1c	Crash prevention
Crash phase	2a	2b	2c	Loss reduction
Post-crash phase	3a	3b	3c	Damage control
Method	Not site specific		Site specific	

This is specified because it has essential meaning for the following treatment stage. This stage can thus include elimination and/or minimization of both accident and injury factors, see the Haddon-Matrix (see table 3.11) which specifies nine different approaches to traffic safety work (Haddon 1970). BSM can include both crash prevention and loss reduction, and this is important to remember also in the stages analysis and treatment.

Method for accident analysis

The approach to accident analysis recommended keeps all the elements of current approaches, but adds new elements that will hopefully make the analysis more conclusive.

Accident analysis should be performed in two stages. The first stage is, by means of detailed examination of accidents, to suggest hypotheses regarding risk factors that may have contributed to the accidents. It should be recognised that an apparent pattern may arise as a result of chance alone. Binomial tests should therefore be applied to determine the probability that a certain number of accidents of a certain type are the result of chance only.

The second stage is to test the hypotheses developed in the first stage of analysis. This can be done by means of a double blind comparison of the incidence of risk factors at each black spot and a comparison location with a good safety record.

The recommended method is illustrated by means of an example (Elvik 2006, 2007).

The first stage of analysis is identical to the current practice of searching for patterns in accident data. It is proposed to formalise this search by relying on statistical tests and pattern recognition methods, as indicated by Kononov (2002).

Table 3.12. Hypothetical results of accident analysis at a black spot (Elvik 2006, 2007).

Accident number	Type of accident	Time of day	Road surface	Vehicles involved	Alcohol involved	Excessive speed	Failure to see
1	Pedestrian	11 PM	Wet	Car	Yes, pedestrian	Yes	Yes
2	Rear-end	10 AM	Wet	Truck	No	No	No
3	Rear-end	5 PM	Dry	Car	No	No	No
4	Pedestrian	8 PM	Dry	Car	No	Yes	No
5	Pedestrian	9 PM	Wet	Car	Yes, pedestrian	No	Yes
6	Pedestrian	11 AM	Wet	Car	No	Yes	Yes
7	Overturning	1 PM	Dry	Motorcycle	No	Yes	No
8	Pedestrian	11 PM	Wet	Truck	Yes, pedestrian	No	Yes
Key finding	Pedestrian: 5	Evening: 4	Wet road: 5	Trucks: 2	Alcohol: 3	Speeders: 4	Did not see: 4
Normal value	Pedestrian: 1	Evening: 5	Wet road: 2	Truck: 1	Alcohol: 1	Speeders: 3	Did not see: 2
P-value (binomial)	0.0011	0.0865	0.0231	0.1963	0.0561	0.2112	0.0865
Predominant accident pattern	The predominant type of accident is a pedestrian accident at night on a wet road surface, in which the parties did not see each other. Some over-involvement of alcohol among pedestrians						

Consider the data presented in table 3.12 as an example. Analysis shows that five of the eight recorded accidents were pedestrian accidents, whereas one would normally expect only one in eight accidents to involve pedestrians. If the distribution of accidents by type is modelled as a binomial trial (each accident is either of the specified type or any other type), it is found that recording five pedestrian accidents in a total of eight accidents is a highly unlikely outcome. The normal probability of a pedestrian accident is 0.125. The probability of observing five pedestrian accidents is only 0.0011, given that one would expect to observe one pedestrian accident out of eight.

Table 3.13. Comparison of the number of accidents normally expected to occur and the actual number of accidents according to three characteristics associated with accidents (Elvik 2006, 2007).

Road user involved	Road surface condition	Alcohol involved	Expected number	Observed number	Ratio observed/expected
Pedestrian	Wet	Yes	0.03	3	96.0
		No	0.22	1	4.6
	Dry	Yes	0.09	0	0.0
		No	0.66	1	1.5
Other	Wet	Yes	0.22	0	0.0
		No	1.53	1	0.7
	Dry	Yes	0.66	0	0.0
		No	4.59	2	0.4
Total	Total	Total	8	8	1.0

Similar tests are reported at the bottom of table 3.12. For each variable recorded, the probability of observing the overrepresented value of that variable is estimated on the basis of the outcome one would normally expect to find.

On the whole, the predominant accident pattern found in table 3.12, pedestrian accidents occurring at night on a wet road surface, suggests that local risk factors related to the amount of pedestrian traffic, road surface friction and visual obstructions may be present at the location.

In table 3.13, the number of accidents normally expected to occur according to all logically possible combinations of values for road user group (pedestrian ($p = 0.125$) or other ($p = 0.875$)), road surface condition (wet ($p = 0.25$) or dry ($p = 0.75$)) and presence of alcohol (yes = 0.125, no = 0.875) has been estimated and is compared to the actual distribution of accidents. It is seen that the combination pedestrian, wet road and alcohol involved occurs much more frequently than one would expect in a random sample of eight accidents.

Despite this, a more careful investigation would be needed in order to determine whether the factors suggested are actually responsible for the abnormally high number of pedestrian accidents at this particular location. Accident analysis at black spots amounts to proposing hypotheses based on known data, which means that the data that generated the hypotheses cannot also be used for testing them. Thus, the principal results of an analysis of accidents should be regarded as hypotheses only, to be tested in subsequent steps of the analysis. These steps can be outlined as follows:

1. For each black spot, find a safer-than-average comparison location, matched as closely to the black spot as possible with respect to variables included in an accident model used to predict the normal number of accidents.
2. For each matched pair of sites, search for local risk factors or safety factors from a list of factors drawn up on the basis of the analysis of accidents at the black spot.
3. Blind analysts to accident records. Analysts should not know which site was black and which site was safer than average.

The use of this approach is shown in table 3.14. Hazardous and safe sites are matched in pairs according to the values observed for the variables included in an accident model. Two matched pairs are shown in table 3.14. Once the pairs have been formed, each site is inspected and data collected regarding local risk factors. A sample of such data, not necessarily exhaustive, is shown in table 3.14.

Table 3.14. Verification of traditional accident analysis by identification of risk factors contributing to accidents (Elvik 2006, 2007).

	Case 1: Local risk factors identified		**Case 2: Local risk factors not identified**	
	Hazardous	**Safe**	**Hazardous**	**Safe**
Matching variables Local risk factors (sample)	AADT, speed limit, number of lanes, number of intersections, trunk road status = nearly same values observed for both sites		AADT, speed limit, number of lanes, number of intersections, trunk road status = nearly same values observed for both sites	
Road surface friction – dry	0.70	0.82	0.78	0.77
Road surface friction – wet	0.25	0.48	0.47	0.49
Pedestrians crossing per day	2,500	1,000	1,200	1,250
Sources of visual obstruction	5	2	3	3
Minimum sight distance (m)	100	155	110	115
Driveways per km of road	2	2	0	0
Public bar nearby	Yes	No	No	No
Accident records:	8 accidents, of which 5 involving pedestrians on a wet road surface	0 accidents	7 accidents, but no clear pattern	0 accidents

In case of the first pair of sites, it was found that wet road surface friction was significantly worse, that there were more pedestrians crossing the road, and more sources of visual obstruction at the hazardous site than at the safe site. This information confirms the hypotheses regarding contributing factors proposed on the basis of the analysis of accidents. The analysis has therefore successfully identified local risk factors. Keep in mind that the analysts identifying risk factors should be blinded to accident records, to prevent their knowledge of accident records from biasing their observations.

The other case shown in table 3.14 was less successful. It turned out that there were no differences between the hazardous and the safe site with respect to the risk factors surveyed. Hence, accidents must be attributed to other risk factors, for example a widespread violation of speed limits or other traffic control devices, or to chance fluctuations.

Based on this logic, criteria can now be proposed regarding the conclusion to be drawn from an analysis of accidents and risk factors at black spots and matched comparison sites. These criteria are shown in table 3.15. A distinction can be made between four cases.

In the first case, factors associated with accidents at the black spot are identified in the accident analysis, and the hypotheses regarding contributing risk factors are supported in the matched comparison. In this case, it is reasonable to conclude that the black spot is a true positive.

In the second case, the accident analysis identified a clear pattern, suggesting that specific risk factors contributed to the accidents, but the subsequent matched-pair analysis of these risk factors does not support these hypotheses. In this case, the analysis is inconclusive. The accidents may be more closely associated with other risk factors than those examined, but they may also be the result of random fluctuations mainly. In a case like this, it is tempting to carry on the analysis by examining one risk factor after the other, until one or more factors are found to be associated with accidents. This practice should be discouraged. It amounts to data mining, which, if carried out long enough, will always turn up something that looks systematic.

Table 3.15. Conclusion drawn from analysis of accidents and risk factors at hazardous road locations and matched comparison locations (Elvik 2007).

Results of accident analysis	Results of matched comparison of risk factors	Conclusion from analysis
A pattern of characteristics associated with accidents is found – hypotheses regarding contributing risk factors are proposed	The hypothesised risk factors are found to be more clearly present at the hazardous location than at the matched comparison location	The hazardous road location is likely to be a true positive site, with a high long-term expected number of accidents
A pattern of characteristics associated with accidents is found – hypotheses regarding contributing risk factors are proposed	The hypothesised risk factors are not found to be more clearly present at the hazardous road location than at the matched comparison location	The analysis is inconclusive; accidents are not found to be the result of the risk factors examined and could therefore be the result of chance or of risk factors not examined
No clear pattern of characteristics associated with accidents is found – hypotheses regarding contributing risk factors are difficult to develop	In a matched comparison with respect to a few risk factors associated with all accidents (speed, friction, lateral placement, following distance) these factors are found to have less favourable values for the hazardous site than the matched comparison site	The hazardous road location is likely to be a true positive site, with a high long-term expected number of accidents
No clear pattern of characteristics associated with accidents is found – hypotheses regarding contributing risk factors are difficult to develop	In a matched comparison with respect to a few risk factors associated with all accidents (speed, friction, lateral placement, following distance) these factors are not found to have less favourable values for the hazardous site than the matched comparison site	The hazardous road location is likely to be a false positive site; that is the accidents are likely to be the result of random fluctuations mainly.

In the third case, the first stage of analysis is "unsuccessful", in the sense that no clear pattern is found and no hypotheses regarding specific risk factors contributing to the accidents can be proposed. The site could, as pointed out by Harwood et al (2002), nevertheless be a true black spot. However, for it to be so, the accidents would have to be mainly associated with fairly general risk factors, i.e. risk factors that are more or less associated with all accidents, and that do not necessarily result in the predominance of a particular type of accident. Risk factors that may contribute to any type of accident include speed, road surface friction, lateral placement of vehicles and the following distances of vehicles. These risk factors are always present, but they could form an unfortunate combination at a particular location. To test if this is the case, one could compare observed values for the general risk factors at a black spot to a matched comparison site. If the values observed were less favourable at the black spot than at the comparison site, it would seem reasonable to conclude that the site is a true black spot.

The fourth case is identical to the third, except that no evidence is found indicating that the general risk factors are contributing to the accidents at the black spot. In this case, it is reasonable to conclude that the site is a false positive, since there is no discernible pattern in accidents, and since no risk factors can be found to be associated with the accidents.

Treatment

Provided that the identified sites are found to be true black spots, the analysis stage is followed by a treatment stage. This stage comprises a presentation and prior assessment of proposals for the minimization or elimination of the problems found. This stage is not treated in this project (cf. figure 1.1).

However, it should be noted that if there is a very clear accident pattern, and strong evidence for risk factors contributing to this pattern, there is usually little doubt about what the most effective treatment will be (Elvik 2006). In addition a lot of troubleshooting tables have been developed, see for example Ogden (1996), PIARC Technical Committee on Road Safety (2003) and Elvik and Vaa (2004).

The prior assessment should include a socio-economic assessment of the proposed solutions and as minimum a qualitative consideration of whether the measures will have a positive, neutral or negative effect on mobility, accessibility, security, aesthetics and noise. The assessment can be made by use of Elvik and Vaa (2004).

3.5.2 Best practice guidelines

As mentioned above research, development and testing of new and better methods for accident analysis has only been done to a minor extent. Therefore, the best practice guidelines are very inspired by the more traditional approaches. The traditional approaches have however been combined with aspects of the state-of-the-art approach.

The analysis methods can be divided into office and field analyses with focus on accidents, the road and its surroundings, the traffic or a combination of the three elements (Sørensen 2007a). Se table 3.16.

Table 3.16. Overall site specific analysis methods divided into office and field analyses.

	Office analyses	**Field analyses**
Accident	– General/statistical accident analysis – Specific/detailed accident analysis – Collision diagram	–
Road	– Condition diagram – Curve analysis	– Inspection – Observation
Traffic	– Traffic analysis (e.g. speed)	– Traffic conflicts
Combination	– Blinded-match-pair-comparison (state-of-the-art)	–

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When conducting analysis and inspection of presumed black spots it is on the one hand important to make detailed analyses of the sites for example by use of all the different analysis approaches. On the other hand it is also important that the analysis stage is not too resource demanding.

Among the different analysis methods the general accident analysis, the collision diagram, the road inspection as well as relevant road and traffic analyses are considered as the most relevant. It is therefore recommended that these methods are used in the analysis stage. In the following, it is specified why and how these methods should be used.

General accident analysis

It is a general recommendation that the analysis stage should include a general or statistical accident analysis (Khisty 1990, Ogden 1996, O'Flaherty 1997, Harwood et al. 2002a, Statens vegvesen 2006 and Sørensen 2006). This analysis is particularly important for sites with many accidents where it is difficult to recognize the accident pattern.

Table 3.17. Circumstances, which should be included in the accident analysis.

Recorded accidents: Number of accidents distributed according to personal injury and damage to property, as well as personal injury distributed according to persons killed, seriously injured and persons with minor injuries
Variation over time: Accident distribution during the day, week, year and accident period
Type of accident: Accident distribution by situation and combination of parties involved
Site: Accident distribution by roadside development, layout of road and speed limit
Circumstances: Accident distribution by weather, lighting conditions, visibility, illumination, state of the roads, accidents in school zones, road works, accidents due to drunk driving, obstacles on or outside the roadway and speed estimate
Means of transport: Accident distribution by element and vehicle
Characterization of persons: Accident distribution by blood alcohol content, gender, age, nationality, illness and use of safety equipment of the parties involved

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In the general accident analysis, information about the registered accidents should be arranged in a way that makes it easy to identify different accident patterns. Depending on quality and quantity of accident data, the data can be described in tables or histograms.

The philosophy underlying the analysis is that frequent accident situations and circumstances indicate problems and similar accidents will probably occur again if nothing is done.

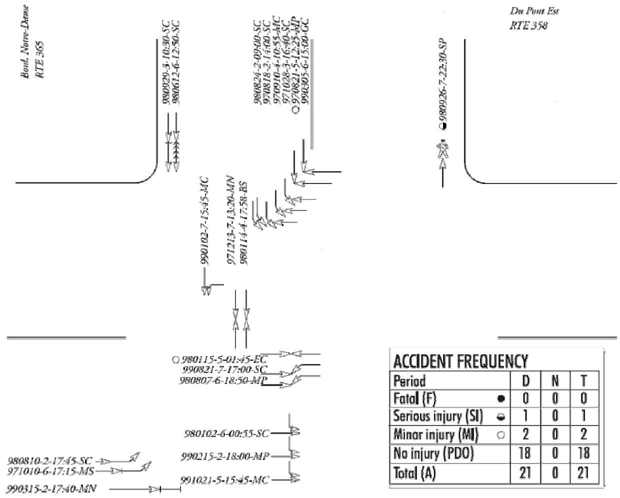
Table 3.17 summarizes what overall circumstances should be included in the general accident analysis. To get an increased focus on severity the analysis should be undertaken for both accidents and injured road users.

Collision diagram

Drawing and analyses of collision diagrams has for many years been a very important analysis tool, and it is still considered as such.

A collision diagram is a graphic representation that displays all the registered accidents at the concerned site, where different parameters of the accidents can be interpreted. This gives a good overview of what accident types are frequent and over-represented at the location. This offers an essential contribution to the identification of traffic safety problems and the assessment of whether the location is a true or false black spot. A collision diagram is shown in figure 3.7.

Drawing of collision diagrams is a resource demanding work, because it normally has to be done manually. To eliminate this problem, pc-based programs for drawing and partly analysing collision diagrams have been developed in for example USA (Harwood et al. 2002a). Such programs can advantageously be used in the analysis stage. Note however that some people working with accident analyses think that the drawing itself is an important part of the analysis (Sørensen 2006).



ACCIDENT FREQUENCY

Period		D	N	T
Fatal (F)	●	0	0	0
Serious injury (SI)	⊖	1	0	1
Minor injury (MI)	○	2	0	2
No injury (PDO)		18	0	18
Total (A)		21	0	21

Figure 3.7. An example on a collision diagram (PIARC Technical Committee on Road Safety 2003).

Normal accident pattern

To identify local risk factors it is not enough to identify possible accident patterns because these can in principle be consistent with the normal pattern for the given type of location. It is hence recommended to compare both the general analysis and the information from the collision diagram with the normal pattern of accidents for the given type of location (Harwood et al. 2002a, PIARC Technical Committee on Road Safety 2003, Overgaard Madsen and Lahrmann 2003, Statens vegvesen 2006 and Sørensen 2007). An overrepresentation of a given accident pattern will indicate that there is a safety problem.

In the state-of-the-art approach, it is suggested that black spots should be compared with a safe location with the same characteristics with regard to traffic and road design. This means that you for every black spot analysed have to find one location, which is very similar to the given black spot. This is very resource demanding. As an alternative, it is recommended that the accidents are compared to a normal pattern, because this is considered less resource demanding.

A given overrepresentation can be a result of chance. Therefore, it is important that at least a qualitative and subjective assessment of the possibility is made.

Road inspection

In spite of the fact that it is very resource demanding it is essential that the in office analyses are supplemented by a road inspection. There are several reasons for that:

- It is important to confirm or invalidate the hypotheses from the previous accident analysis to increase the reliability of the analysis stage and to assess whether the given site is a true or false black spot.
- It is important to identify problems that do not appear from the accident analysis and hence give the analysis stage a more prospective perspective.

- It is important to make it independent of a typically low and skew level of reporting in the official accident statistics.

The road inspection should be made relatively formalized to ensure objectivity, completeness, reproducibility, comparability and good opportunity for further treatment and documentation. To ensure that the use of checklist is recommended. For that purpose, many checklists have been development (Ogden 1996, Gaardbo and Schelling 1997, PIARC Technical Committee on Road Safety 2003 and Statens vegvesen 2006a).

Traffic and road analyses

The accident analysis and the survey should be supplemented by traffic counts for the primary road and relevant side roads, speed measurements and possibly some relevant road analyses according to specific themes. It could for example be measurement of road friction.

True or false black spots

As described already it is very important that the analysis stage tries to determine whether the identified sites are true black spots or sites that erroneously have been identified due to a randomly high number of accidents in the identification period. This assessment is always important, but it is especially important if the state-of-the-art approach for identification is not used.

For assessing, whether identified sites are true black spots there are four sources of information, i.e. the result of the identification, the results of the accident analysis (general analysis and collision diagram), the results of the road inspection and finally the result of the traffic and road analyses.

Based on this information it is recommended that the assessment be done by comparing the results from the accident analyses and the road inspection. The accident analysis is used to generate hypotheses about risk factors contributing to accidents, while the road inspection is used to test these hypotheses. Conformity between the results from these analyses will indicate that the given site is a true black spot.

A problem with this approach is that the analyst's expectations from the accident analysis can influence and bias findings in the road inspection (Elvik 2006). To avoid this problem the two analyses can be done by two independent engineers like it is done in the BSM in Switzerland (Elvik 2007).

In addition, the comparison of the results from the accident analysis and the normal pattern of accidents for the given type of location will indicate whether the given site is a true black spot.

There is always a risk that the assessment will not be correct, but the point is that it is better to make an active and relatively systematic assessment with a risk of some mistakes than refrain from doing the assessment because the demands for doing the state-of-the-art approaches can not be satisfied. In this context it is recommend that the assessment be recorded in the report of the analysis, because it ensures an active assessment.

3.5.3 Implementation steps

To make the described methods for analysis black spots possible it is necessary to make a comparison with safe sites or normal accident pattern possible.

Comparison with safe sites

In the state-of-the-art approach for black spot analysis, it is recommended that the black spots should be compared with a safe location with the same characteristics with regard to traffic and road design. To make this comparison possible several steps have to be taken:

- *Identification:* An identification of locations that are safer than the average (sometimes also named as white spots) has to be made. Safe locations can be defined as the opposite of black spots, i.e. sites that have a smaller expected number of accidents, than other similar locations as a result of local safety factors. The procedure for identifying these locations is in principle the same as the procedure for identifying black spots as described in chapter 3.3. Like black spot identification, the identification of safe spots can be done by more or less advanced model based identification methods, i.e. like the state-of-the-art approach or like the best practice guidelines.
- *Matching:* Each identified black spot has to be matched as closely as possible to a similar safe location with regard to variables included in the accident prediction model used to predict the normal number of accidents.
- *Supplemental data collection:* A supplemental collection of relevant data for analysis of the matched locations has to be made for each matched pair of sites. First, it has to be decided what data are relevant to compare and secondly the collection itself has to be done. The data collection can be done by use of relevant databases and visiting the sites. Note that the data obviously have to be collected for both the black spot and the safe spot. The collection can for example consist of data about road surface friction, pedestrians crossing per day, sources of visual obstruction, minimum sight distance, driveways per km of road and public bar nearby.
- *Procedure for blinded analysis:* A procedure for blinded analysis should be established so it is secured that the analysts do not know which site was black and which site was safer than average.

Comparison with normal accident pattern

The procedure for blinded matched-pair comparison is relatively resource demanding. As a replacement, it is therefore as best practice guidelines recommended to make a comparison with a normal accident pattern, which is considered less resource demanding.

However, this comparison requires that the normal accident pattern is known and that the given black spot belongs to the same type of location as that used in the calculation of the normal accident pattern.

It is recommended that the categorization of sites and the calculation of the normal accident pattern for these sites should be done by a central authority for whole the public road system and made available for all on for example the internet.

3.6 Evaluation of the black spot treatment

Systematic evaluation of the effectiveness of black spot treatment is essential. For too long, the complexity of this task has been underestimated by researchers. As a result, a number of methodologically flawed evaluations have been made (Elvik 1997). In following it is summarized how the black spot treatment should be evaluated, and what should be done to implement this recommendation.

3.6.1 State-of-the-art approach

Evaluation of the effects of black spot treatment should employ the empirical Bayes before-and-after design. The argument for that is that the empirical Bayes method makes it possible to control for (a) Local changes in traffic volume, (b) Long term trends in accidents, and (c) Regression-to-the-mean. If accident migration is an issue, an attempt to control for it should also be made.

However, it should be recognised that application of this method is not always straightforward and that if it is inappropriately applied, it can produce misleading results (Persaud and Lyon 2007).

The data presented in table 3.9 can be used to develop a simple example of the use of the Empirical Bayes method in a before-and-after study. Suppose sites that recorded four or more accidents are regarded as black spots. There are 66 such locations. Further, suppose that 35 are selected for treatment, 31 are not. The 35 sites selected for treatment includes all 28 correct positives and seven of the false positives. This assumption is reasonable, as even state-of-the-art techniques for accident analysis cannot guarantee that only correct positives are selected for treatment.

Sites selected for treatment had a total of 183 accidents before treatment, of which 148 at the correct positives and 35 at the false positives. The remaining false positives, not selected for treatment, had 151 accidents. In this data set, regression-to-the-mean is known (since accidents are assumed to be Poisson-distributed around the various mean values). The true long-term-expected number of accidents, after controlling for regression-to-the-mean, can be estimated to 112 for the correct positives (recorded 148), 21 for the false positives (35 recorded) and 90 for the false positives not selected for treatment (recorded 151).

It will be assumed that treatment is only effective for the correct positives, reducing their expected number of accidents by 25% (from 112 to 84). No effect is assumed for the false positives selected for treatment, nor for the other false positives.

Table 3.18. Results of different hypothetical before-and-after study (Elvik 2007).

Technique	Recorded before	Expected after	Recorded after	Estimate of effect
Simple before-and-after	183	183	105	-43%
Before-and-after, non-treated as comparison	183	109	105	-4%
Empirical Bayes before-and-after	183	122	105	-14%
True situation	183	133	105	-21%

Table 3.18 summarises the findings expected by various techniques for before-and-after studies. The true situation, as determined from the hypothetical data, is a decline from a long-term expected number of accidents of 133 to 105, an accident reduction of 21%.

If a simple before-and-after study is made, not controlling for regression-to-the-mean, the effect of the treatment will be considerably overstated (estimated to 43% versus the correct value of 21%).

If the non-treated black spots are used as comparison group, the effect of the treatment will be underestimated. The ratio of after to before accidents in the comparison group (90/151) is used as a “control ratio” and multiplied by the recorded number of accidents before in the treated group (183), yielding an expected number of accidents of 109. This will over-adjust for regression-to-the-mean, as a stronger regression-to-the-mean effect is expected for the non-treated sites than for the treated sites.

The Empirical Bayes technique was implemented by predicting the expected number of accidents according to the following expression:

$$[(0.779/2.003) \cdot 0.779] + [(1 - (0.779/2.003)) \cdot X], \text{ where}$$

X: The recorded number of accidents in the before-period

As can be seen from table 3.18, the EB-method does slightly underestimate the true effect of the treatment, but it comes closer than any of the other techniques.

The source of the error in this case is that the EB-prediction is based on a considerably more heterogeneous population of sites than those that are considered for black spot treatment. This means that the variance exceeds the mean and that the slope parameter of the EB-predictions (the expression within the first brackets above) becomes too low. This, in turn, underlines the importance of basing EB-predictions on a reference group that is as similar to the treated group as possible (Persaud and Lyon 2007). The use of accident prediction models as part of the EB-method may help in this regard.

3.6.2 Best practice guidelines

Use of the empirical Bayes before-and-after design requires good data and relatively comprehensive statistical analyses, and like the other stages of the BSM it can hence not always be done like described in the state-of-the-art approach. In addition, the state-of-the art approach for evaluation can only be applied if the empirical Bayes method is used in the identification stage, which is still rarely the case.

Criteria for doing the evaluation

Despite the mentioned data limitations, evaluations are demanded anyway and the question then is what to do. In principle, there are two options (Elvik 2006a):

1. Do the evaluation by use of the second or third best method (the best practice guidelines) like it is recommend for the other stages of the work.
2. Refrain from doing the evaluation at all.

The first opportunity is recommended in the other stages of the BSM based on the philosophy that it is better to do something rather then refrain from doing anything, because the worst that can happen is that the work does not have any effect. It is assumed that people working with traffic safety know so much about the subject that measures that will increase the number and severity of accidents are not used.

The evaluation stage of the BSM differs in a way from the previous stages because measures have been implemented, and the objective of this stage is to get further knowledge about the effects of the measures. In contrast to the previous stages, it is not regarded as appropriate just to do something because no knowledge must be considered as better than to have wrong knowledge. In a situation where the data and resources are very limited and near to impossible to obtain it is thus recommended that the evaluation studies are not done.

How "bad" evaluation studies we can tolerate has been discussed by Elvik (2006a). He has formulated the following nine criteria to assess the given evaluation:

1. *Statistical relationship (3):* A good evaluation should be able to detect an effect of a size that has practical interest.
2. *Strong relationship (1):* A strong effect is more likely to be causal than a weak effect.
3. *Internally consistent relationship (1):* A good evaluation should be able to measure the internal consistency of an effect.
4. *Clarity of causal direction (5):* A good evaluation should be able to make an unambiguous determination of the causal direction.
5. *Control for confounding (30):* A good evaluation should control for all confounding factors.
6. *Analysis of causal mechanism (5):* A good evaluation should identify the mechanism that produces the effect.
7. *Support by theory or other studies (5):* A good evaluation should be based on theory or results from other studies.
8. *Dose-response relationship (5):* A good evaluation should show any Dose-response relationship.
9. *Specificity of effect (5):* A good evaluation should show specificity of effect.

The different criteria are not equally important and different weights/points have been assigned to the criteria to reflect their importance. How many points fulfilment of a criterion may give are specified in parenthesis.

It is recommended that these criteria are evaluated when making an evaluation study where the state-of-the-art approach is not used.

Different traditional evaluation studies

The more traditional and simple evaluation studies can be divided into the following three types (Hauer 1997, Overgaard Madsen 2005a):

1. Naive before-and-after studies
2. Before-and-after studies using a comparison group
3. Evaluation studies based on traditional accident models

However, none of the three approaches is directly recommended as best practice guidelines for evaluation of the effects of the black spot treatment, because they all have some essential deficiencies.

Instead, it is recommended to use a kind of combination of especially the first two approaches to try to compensate for the disadvantages of the different methods.

More specifically, it is recommended to make a before-after-study, which controls for long-term trends in the number of accidents, local changes in traffic volume and regression-to-the-mean by use of the correction factors C_{trend}, $C_{traffic}$ and C_{reg} (Overgaard Madsen 2005a).

By use of the correction factor $C_{trend,}$ you correct for the influence of long-term trends in the number of accidents as a result of more safe vehicles, traffic safety campaigns, better road users etc. The factor is estimated on basis of the trend in the number of accidents for comparison locations where the given measure has not been implemented.

The factor $C_{traffic}$ corrects for the influence of local changes in traffic volume. The factor can be estimated by use of traditional accident models if such are available. However, it should be noted that the correction only should include changes that have nothing to do with the given measure (Amundsen and Elvik 2004).

The last factor C_{reg} controls for the influence of regression-to-the-mean. However, this cannot be estimated by use of simple accident history. Instead, it is suggested that it is decided arbitrarily. By experience, the factor is assumed to be around 0.7-0.8 for black spot work in Denmark (Greibe and Hemdorft 2001). It should be noted that this is a very simple assumption, because the regression-to-the-mean will vary a lot from location to location, and it should thus be assessed individually for each location (Hauer 1997, 2001, Vistisen 2002).

In overall terms, it is suggested that the effects of the black spot treatment are estimated by use of the following formula (Overgaard Madsen 2005a):

$$\text{Effect} = \frac{(\text{Average number of accidents, after})}{(\text{Average number of accidents, before}) \cdot C_{trend} \cdot C_{traffic} \cdot C_{reg}}$$

Despite the use of correction factors, it should be noted that there still is a considerable risk of making a wrong estimate of the effect, but the method is considered as the best practice guideline when the data and the resources for the evaluation study are limited.

3.6.3 Implementation steps

To implement the state-of-the-art approach for before-and-after studies of black spot treatment it is a necessary precondition that the empirical Bayes method for estimating the local expected number of accidents has been developed and used in the identification stage.

If that is not the case, it is not immediately possible to make such an evaluation, and the evaluation should be made as described in the best practice guidelines. For implementing these guidelines, it is necessary to make the calculation of the correction factors C_{trend}, $C_{traffic}$ and C_{reg} possible.

To calculate the correction factor C_{trend} requires that it is possible to match the black spot to a representative group of similar locations and that the accident history is known for these locations. This is in principle the same matching procedure as when the black spot is compared with a safe location or the normal accident pattern for a similar group in the accident analysis.

The second correction factor $C_{traffic}$ can be estimated by use of traditional accident models. This means that such models have to be available. These are available if the second best method for identifying black spots described in chapter 3.3.3 has been implemented.

The last correction factor C_{reg} cannot immediately be estimated, when the state-of-the-art approaches not have been implemented in the earlier steps of the BSM. Therefore, it is necessary to make a more or less detailed arbitrarily determination of the size of the factor. It is to prefer that this rough estimate be made as individually for each location treated as possible.

3.7 Summary

Black spot management (BSM) has a long tradition in traffic engineering in several countries, and it is still considered as a very essential part of site-specific traffic safety work. No standard definition exists of black spots, but from a theoretical point of view, black spots should be defined as any location that:

1. Has a higher expected number of accidents,
2. Than other similar locations,
3. As a result of local risk factors.

Black spots should not be defined in terms of the recorded number of accidents because observed variation in accidents is always a mixture of random and systematic variation, and it is sources of systematic variation we are looking for in safety analyses.

The philosophy in BSM is to use the accident history to identify locations with local risk factors that are related to the local detailed road layout. These locations can be treated relatively inexpensively because it is only the detailed road layout and traffic behaviour that have to be changed and not the general road layout. Therefore, you get a lot of value for money used in terms of traffic safety.

BSM can be divided into 10 more or less independent stages as described in figure 1.1. BSM starts with a systematic collection of data that enable the identification of black spots. Once black spots have been identified, accidents are analysed in order to find a common pattern of accidents and factors that contribute to accidents. The objective of the analysis is to identify factors contributing to accidents that may be amenable to treatment. If this analysis is not successful, it will be concluded that the black spot is likely to be false and no treatment will then be implemented. If, on the other hand, a treatment believed to be effective is found, it should be implemented and its effects evaluated.

3.7.1 State-of-the-art approach and best practice guidelines

Table 3.19 summarizes the characteristics of the state-of-the-art approach and the best practice guidelines for BSM.

Table 3.19. Characteristics of the state-of-the-art approach and the best practice guidelines for black spot management (BSM).

	State-of-the-art	Best practice
Classification of sites	– Dividing of road system into clearly defined sites	– Same as state-of-the-art
Identification principle	– The empirical Bayes method	– Simple model based method
Identification criterion	– Higher expected accident number than the normal expected number – Severity is not included	– The absolute difference criterion – Predefined number or a certain share – Severity is not a part of the identification
Analysis	– Binomial tests of accident patterns – Blinded matched pair comparison	– General accident analysis, collision diagram, inspection, traffic and road analyses – Comparing with normal accident pattern – True/false assessment
Evaluation	– Empirical Bayes before-and-after design – Should always be made	– Before-after-study with correction for trends, traffic and regression – Should not always be made, it depends of data

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Black spots should be identified by reference to a clearly defined population of roadway elements as for example curves, bridges or four-leg junctions. This makes it possible to estimate the general expected number of accidents by use of an accident model. Use of a sliding window approach should be avoided, because it has been found to greatly inflate the number of false positives.

The identification of black spots should rely on a more or less advanced model based method, ideally speaking the empirical Bayes method.

In the empirical Bayed method, the expected number of accidents on a specific location is estimated as a weighted average of the registered number of accidents on the location and the general expected number of accidents for similar sites estimated by accident prediction models.

The argument for using model based identification methods are that they are the best to make reliable identification of sites with local risk factors related to road design and traffic control, because systematic variation and partially random fluctuation are taken into consideration.

Black spots should be identified as sites that have a higher expected number of accidents than the normal expected number on similar roadway elements due to specifically local risk factors. In the best practice guidelines, this is clarified. Thus, the identification criterion should either be a predefined number that the absolute difference between the expected and normal number of accidents (the savings potential) has to exceed or a certain percentage of the road network with the largest savings potential.

The state-of-the-art approach for accident analysis consists of two stages. The first stage is, by means of detailed examination of accidents, to suggest hypotheses regarding risk factors that may have contributed to the accidents. The second stage is to test the hypotheses developed in the first stage of analysis. This can be done by means of a double blind comparison of the incidence of risk factors at each black spot and a comparison location with a good safety record.

According to the best practice guidelines, the analysis stage should as a minimum consists of a general accident analysis, a collision diagram, a road inspection and relevant traffic and road analyses. The general accident analysis and the collision diagram should be compared with the normal pattern of traffic accidents for the given type of location. Finally, an active and written assessment of whether the presumed black spot is a true black spot or not should be made.

Evaluation of the effects of the treatment should employ the empirical Bayes before-and-after design, because it controls for local changes in traffic volume, long term trends in accidents and regression-to-the-mean.

If it is not possible to make an empirical Bayes before-and-after evaluation, the evaluation should be made as a simpler before-after-study controlling for long-term trends in the number of accidents, local changes in traffic volume and regression-to-the-mean by use of correction factors.

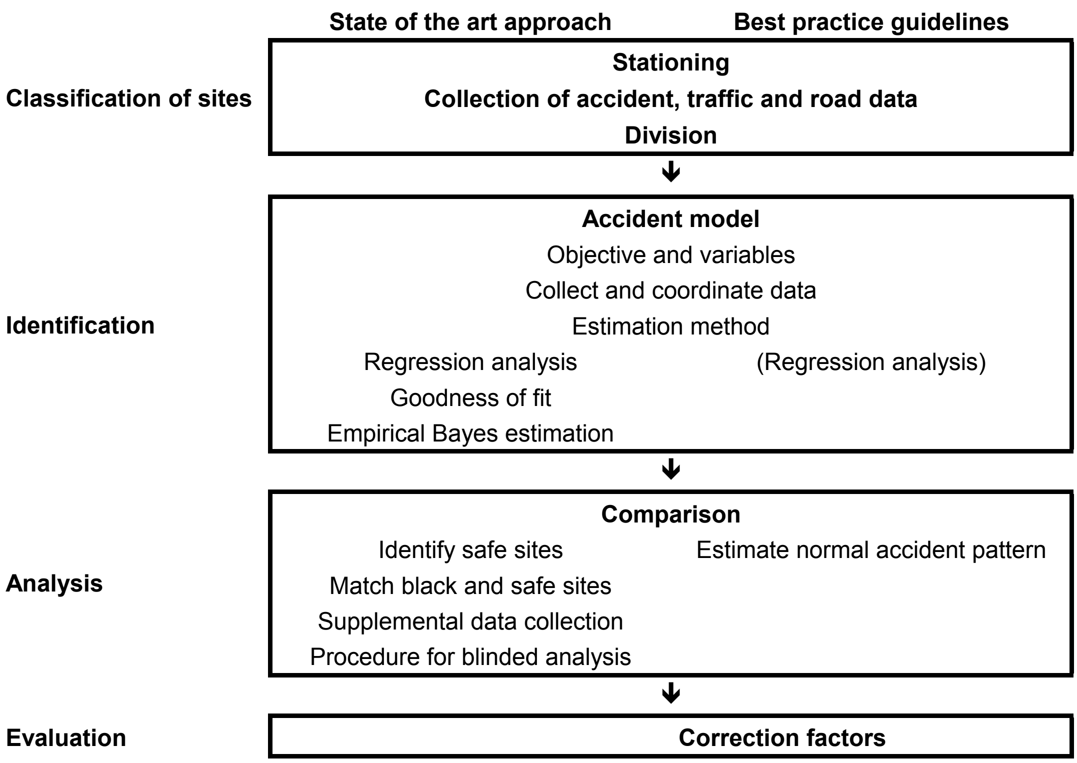

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Figure 3.8. Implementation steps for the state-of-the-art-approach and the best practice guidelines for different stages of BSM.

3.7.2 Implementation steps

Figure 3.8 summarizes the implementation steps for the state-of-the-art approach and best practice guidelines for different stages of BSM.

Data

BSM is a reactive tool. This means that it is based on the accident history. Therefore, the presence of accident data is a fundamental precondition for the work. These accident records have to contain adequate information about locality, accident type, severity, time, road elements and the surrounding environment, circumstances and vehicles involved.

Information about traffic accidents is normally registered by the police. This is to a large extent already done in all European countries. However, the records have a varied quality. The primary problem is low level of reporting (Elvik and Mysen 1999). If the level is too low, BSM cannot be done as described in this report. To improve the accident databases the police recorded accidents could be supplemented with hospital recorded traffic accidents.

In addition to information about accidents, data about traffic volume, road design and the surrounding environment are also needed to make a classification of sites into a clearly defined population of roadway elements and to make a model based identification. These data should be registered by the road authorities.

All the data have to be unambiguously located on the road network by use of for example stationing along all roads in the road network. In addition, the data have to be immediately interoperable with each other so that it is possible to make an analysis of the correlation between the different data.

Accident model

Black spots should be identified by a more or less advanced model based method. The development of such a model could be summarized in the following steps:

1. *Objective and field of application:* What should the model be used for and what is the level of ambition and economic resources for the work.
2. *Dependent and independent variables:* Identification and selection of possible dependent and independent variables in the model.
3. *Collection of data:* Collect and coordinate data for the chosen possible independent and dependent variables. i.e. data about traffic volume, roads and the surrounding environment respectively data about accidents.
4. *Choice of method for estimation:* Should the model be estimated as a combined category and regression analysis or a multivariate regressions analysis and what assumption should be made about the distribution of the residual terms.
5. *Regression analysis:* Analysis of what possible independent variables should be included in the model and estimation of relevant regression coefficients.
6. *Goodness of fit:* Evaluation of the developed accident models ability to explain and estimate the systematic variation in the accident counts.

7. *Empirical Bayes estimation:* Estimation of the expected number of accidents by combining the model estimated number of accidents with the registered number of accidents on each location by use of the empirical Bayes approach.

In the state-of-the-art approach, it is necessary to go through all seven steps. In the best practice guidelines, it is only necessary to take the five first steps if a simple accident model is used and the four first steps if a category analysis is made.

Comparison

In the black spot analysis, it is recommended that the black spots should be compared with a safe location or a normal accident pattern. To make this comparison possible several steps have to be taken:

- *Identification:* Identifying locations that are safer than the average. The procedure is in principle the as the procedure for identifying black spots.
- *Matching:* Each identified black spot has to be matched as closely as possible to a similar safe location.
- *Supplemental data collection:* A supplemental collection of relevant data for analysis of the matched pair of locations.
- *Procedure for blinded analysis:* A procedure for the analysis should be made so it is secured that the analysts do not know which site was black.
- *Normal accident pattern:* Estimation of the normal accident pattern and matching of the black spot to a relevant pattern.

Correction factors

To implement the state-of-the-art approach for before-and-after studies of black spot treatment it is a necessary precondition that the empirical Bayes method is developed. If not, it is necessary to make a calculation of C_{trend}, $C_{traffic}$ and $C_{reg.}$

4 Safety analysis of road networks

This chapter summarizes the state-of-the-art approaches and the best practice guidelines for safety analysis of road networks also named as network safety management (NSM). Like the previous chapter, the key elements with regard to classification of roadway elements, identification principle, identification criterion, accident analysis and evaluation of the treatment are summarized. For further clarification of the elements in the state-of-the-art approach and in the best practice guidelines reference is made to Elvik (2007) respectively Sørensen (2007).

After the description of the different elements of the state-of-the-art approaches and the best practice guidelines it is discussed and recommended how the approaches can be implemented.

4.1 What is safety analysis of road networks?

Just as different terms for black spots are used, different terms for road sections identified in NSM are also used. Thus, Sørensen (2006) has counted more than 20 more or less different terms in a review of international historical and scientific articles, reports and textbooks about NSM. Inspired by Hauer (1996) the terms are divided into negative terms like hazardous road sections, dangerous roads or problem roads, more neutral terms like grey or red road sections, accident prone locations, one star roads or roads for safety investigation and finally some positive terms like roads with safety potential and promising roads. The most common and frequently used term for road sections identified in NSM is hazardous road sections. This term will hence consistently be used in this report.

4.1.1 Definition and philosophy

Like black spots, no international standard definition of hazardous road sections exists (Sørensen 2006). In addition no definitions have been explicitly formulated with the exception of a few references as Thorson (1970), Deacon et al. (1975), Joly et al. (1992), Sayed et al. (1995, 1997), Ogden and Taylor (1996), Vejdirektoratet (2002) Hummer et al. (2003) and Sørensen (2006, 2006a). According to OECD, it is also very difficult or maybe impossible to make a simple and short definition of hazardous road sections because it is necessary to include many parameters in the formulation (OECD Road Research Group 1976). However, definitions can indirectly be interpreted from the identification method (May 1964). For example, there is no explicit definition on hazardous road section in the Norwegian NSM, but the definition can be interpreted from the identification methods as road section where the expected so called injury severity density exceeds 1.2 and accidents resulting in fatal or serious injury have been recorded during the last eight years (Ragnøy et al. 2002).

Based on the explicitly formulated definitions, interpretation of current method and common understanding about NSM it is concluded that hazardous road sections most often are defined in the same way as black spots (Sørensen 2006). This means that hazardous road sections can be defined as any section at which the site specific expected number of accidents is higher than for similar sections, due to local and section based risk factors present at the site. In addition, this definition should not only include the number of accidents but also severity (Elvik 2007).

However, this way to define hazardous road sections has been exposed to criticism among others from Sayed et al. (1995, 1997), Kononov (2002) and Hummer et al. (2003).

Sayed et al. (1995, 1997) and Kononov (2002) argue that the definition and the identification method should be based solely on site-specific accidents through specific accident themes or types or accidents associated with road related risk factors because this will remove all interference from not site specific accidents already at the identification stage. This means that the link between the different stages in NSM will be improved, because the analysis in a way already is started during the identification stage. It can be argued that this will give a more effective traffic safety work compared to the normal division of the work into different more or less independent stages.

However, in this project it is not recommended to use an accident specific definition. The reasons are the following:

- A significantly high number of accidents at a location compared to similar locations must indicate, that there are local risk factors and it is thus unnecessary to limit the identification to road related accidents to find sites with road related traffic safety problems (Thorson 1970).
- An accident specific definition and identification requires a relatively comprehensive identification stage, because it for example has to be analysed what accidents have road related risk factors. However, the normal procedure and philosophy for NSM and BSM is that the identification should demand relatively little resources (Thorson 1970, Hauer et al. 2002).
- An accident specific definition and identification will limit the accident data, which already are limited in many countries due to incomplete accident reporting (Elvik and Mysen 1999).
- The focus on some certain themes or accident types can result in the failure to identify other traffic safety problems at the concerned sites. It will for example fail to identify problems with drink driving which is not a distinctly road related problem. However, the consequence of for example drink driving accidents can be minimized by using road related measures to make so called forgiving roads and surroundings.

Another criticism of the typical definition of hazardous road sections is that cost effectiveness is not directly included in the definition (Hummer et al. 2003).

However, this is more or less indirectly included in the typical definition, because the primary focus is on local detailed road layout and traffic behaviour, which can be treated relative inexpensively because it is only the detailed road layout and traffic behaviour that have to be changed and not the general road layout. To include cost effectiveness directly in the definition and identification will also result in a very comprehensive identification stage because an accident analysis and suggestion for treatment in principle have to be made as a part of the identification.

Based on this discussion the following definition of hazardous road sections is used and recommended in this project. A hazardous road section is any section that:

1. Has a higher expected number and severity of accidents,
2. Than other similar road sections,
3. As a result of local and section based accident and injury factors.

Based on this definition of hazardous road sections it seems that the basic philosophy for NSM is the same as the philosophy for BSM. This is true with regard to how it is decided what locations should be analyzed and treated. Nevertheless, there are also some differences in the basic philosophy for NSM and BSM. These differences are clarified in the following.

4.1.2 Differences between BSM and NSM

BSM and NSM primarily differ from each other with regard the basic philosophy for the work, but also with regard to the length of the locations, inclusion of severity and the frequency of the work. This is summarized in table 4.1 and will be clarified in the following.

Table 4.1. Overall differences between BSM and NSM.

	BSM	NSM
Philosophy	– A remedial and retrospective nature	– Both a remedial and retrospective nature and a preventive and prospective nature
Severity	– Not included in the identification	– Included in the identification
Length	– Up to about 0.5 kilometres	– Between 2 and 10 kilometres
Frequency	– Every or every second year	– Every second to fourth year

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The difference between BSM and NSM with regard to basic philosophy for the work is that BSM has a remedial and retrospective nature, while NSM typically both has a remedial and retrospective nature as BSM and a preventive and prospective nature comparable to the approach in mass action. NSM has a remedial and retrospective nature because the identification stage is based on accident history. The more preventive and prospective nature you see in the following analysis and improvement stages because they typically are based on both accidents and general traffic safety problems and standard improvements. You could say that the idea is that remedial improvements on accident locations are spread out on the whole road section and thereby also get a preventive and prospective nature (Sørensen 2006, 2006a).

It should be noted that this general philosophy for NSM has been examined for nine hazardous road sections on main roads in rural areas in Denmark. On these road sections, several faults and deficiencies with regard to traffic safety have been identified and different solutions to eliminate or minimize the problems have been proposed and implemented. However, an examination of the more than 100 solutions proposed shows that more than 75 % of these only are of a preventive and prospective nature because they only relate to problems identified during the road inspection. There are thus only few proposed solutions, which both have a remedial and retrospective nature and a preventive and prospective nature through relating to problems identified in both the accident analysis and in the road inspection (Sørensen 2006, 2006a).

This shows that it is very difficult to find local and road section based accident factors based only on accident history. The analysis of the road sections is thereby to a greater degree in the nature of a general road examination with special attention to standard improvements rather than treatment of local and road section based accident factors.

There is no doubt that general road examination and standard improvements contribute to traffic safety improvements, but since the standard improvements in principle are independent of the accident history the ranking may be done in a better way as a non accident based method. The basic philosophy to combine retrospective and prospective nature could thus be questioned because the resources maybe can be used in a better way for road examination and standard improvements. To provide a complete answer to this question that applies to the situation in all European countries further research is required.

The second difference between BSM and NSM is the attention to accident severity. Accident severity should not be a part of the black spot identification itself, whereas it should be an integrated part of the identification of hazardous road sections. The argument is that longer sections with more accidents permit a more meaningful consideration of accident severity than short sections and intersections with fewer accidents.

The third difference is obviously the length of the road elements considered. Black spots normally have a length of up to 0.5 kilometres, while hazardous road sections according to the recommendations in Sørensen (2007) have a length of between 2 and 10 kilometres, with an average section length of around 5-6 kilometres.

The last overall difference is how often the work should be done. BSM is normally performed every or every second year. Likewise, it is recommended that NSM is recurring at regular intervals. However, the intervals for NSM should probably be longer for NSM than BSM because the workload of analysis and making suggestions for treatment is larger for hazardous road sections than black spots.

It is very important that the people working with BSM and NSM are aware of these differences because it has important implications with respect to how the work in practice should be done. This means that NSM should not be done like the usual routine for BSM although there are many common characteristics.

4.1.3 Current methods

In Elvik (2007), a survey was conducted to describe how hazardous road sections are identified, analysed and treated in Germany, Norway and the United States. This is summarized and discussed in the following. In addition, a suggestion for a Danish method for main roads in rural areas is described. Note that this suggestion has not been implemented.

Denmark

The road system is divided into homogenous sections regarding annual average daily traffic, type of road, number of lanes, roadside buildings, speed limit and presence of bicycle lanes and side strips. In order to make sure that the sections are homogenous, the sections may have different lengths. It is recommended that the lengths are between two and 10 kilometres.

The identification of hazardous road sections is based on the so called reduction potential index (RPI), which is estimated as the absolute difference between the recorded accident cost weighted density of accidents for the given road section, and the average accident cost weighted density of accidents for the category to which the road section belongs.

The calculation of recorded and average accident cost weighted density of accidents is based on density of accidents with severe personal injury, minor personal injury and damage to property, weighted according to the average accident costs for the three categories of accidents. The calculations of both the recorded and the average accident cost weighted density are done by use of a five years accident period.

Hazardous road sections are identified as sections with RPI larger than four.

In the analysis stage, the identified road sections have to be analysed in order to ascertain whether they are true hazardous road sections, and, if so, why they are hazardous.

The accident analysis consists of a general accident analysis as well as an extended collision diagram. The extended collision diagram covers a traditional collision diagram, which has been amplified with information from the general analysis. This is done to allow the identification of local problems, which “drown” in the average of the road section as such. Both results from the general accident analysis and the extended collision diagram have to be compared with the normal accident pattern for similar road sections. The accident analysis is to be supplemented by a road inspection and relevant analyses of traffic and road features.

Provided that the identified sections are found to be true hazardous road sections, proposals for countermeasures have to be made and assessed.

For further details about the method, see (Sørensen 2006, 2006a, 2007a).

Germany

The road network is divided into road sections that more or less have the same traffic volume, the same cross section and the same type of environment. The road sections are around 10 kilometres and at least 3 kilometres long.

A distinction is made between three levels of accident severity. That is serious injury accidents, which includes fatal accidents, slight injury accidents and property-damage-only accidents. Four indicators of safety performance are used to identify hazardous road sections:

1. *Accident density:* Number of accidents per kilometre per year
2. *Accident cost density:* Societal cost of accidents per kilometre per year
3. *Accident rate:* Number of accidents per million vehicle kilometres
4. *Accident cost rate:* Societal cost of accidents per million vehicle kilometres

All these indicators are stated in terms of the recorded number of accidents during a period of three to five years. No attempt is made to adjust for possible random fluctuations.

To identify road sections with poor safety performance, accident cost density is used. As resources are limited, those sections where improvements can be expected to have the highest benefit-cost ratio should be treated first. Therefore, information is needed on the accident costs per kilometre and the safety potentials for possible remedial measures.

The safety potential (SAPO) is defined as the amount of accident costs per kilometre that could be reduced if a road section had a best practice design. The higher the safety potential the more societal benefits can be expected from improvements of the road. SAPO is calculated as the difference between the current accident cost density (ACD) and the basic accident cost density (bACD), which represents the anticipated average annual number and severity of accidents, which can be achieved by a best practice design.

The sections of the road network are ranked according to the magnitude of the safety potential. Sections with a high rank are selected for more detailed engineering study designed to propose safety measures. It is recommended to present the results of the analysis in diagrams. The initial stages of this analysis are identical to the analysis of black spots with the exception that no sites visits are performed.

For further details about the method, see (German Road and Transportation Research Association 2003).

Norway

The Norwegian approach is performed for the national roads, which were divided into one-kilometre road sections.

The identification method is based on the concept of injury severity density (ISD), which is defined by the formula:

$$\text{ISD} = \frac{33.20 \cdot \text{FAT} + 22.74 \cdot \text{CRI} + 7.56 \cdot \text{SER} + 1.00 \cdot \text{SLI}}{\text{Km} \cdot \text{year}}, \text{ where}$$

FAT = Fatally injured road users

CRI = Critically injured road users

SER = Seriously injured road users

SLI = Slightly injured road users

The levels of injury severity are based on official Norwegian road accident statistics, and the weights assigned to each level of injury severity are proportional to the societal costs of one injury of the stated severity.

In order to develop unbiased estimates of injury severity density for any road section, the empirical Bayes method was applied. In order to apply the empirical Bayes approach, multivariate models were fitted to explain the number of injured road users. The dependent variable in the models fitted was the number of injured road users of a given injury severity per kilometre during a period of eight years. Separate models were fitted for each level of injury severity. Annual average daily traffic, speed limit, the type and status of road, number of lanes and number of junctions per kilometre were used as explanatory variables in the models.

Hazardous road sections are identified as those 10% of all national roads that have the highest values for expected injury severity density, and where accidents resulting in fatalities or serious injuries have been recorded during the last eight years.

Once hazardous road sections are identified, an analysis of accidents is performed, using routinely available data only and not visiting each section. The objective of the accident analysis is to identify those accidents that make the greatest contribution to injury severity density. As part of the accident analysis, accidents were described according to type of accident, road surface condition, weather conditions and light conditions. The analysis of accidents was based on the recorded number of accidents, or, more precisely, on the number of injured road users, specified according to injury severity in each type of accident.

For further details about the method, see (Ragnøy et al. 2002, Ragnøy and Elvik 2003).

The United States

The United States Federal Highway Administration has developed a comprehensive software system for NSM called Safety Analyst, which consists of four modules: Network screening, diagnosis and countermeasure selection, economic appraisal and priority-ranking and evaluation.

The basic purpose of the network screening module is to use available data about geometric design features, traffic control features, traffic volume, accident history and characteristics and safety performance functions to review the entire roadway network under the jurisdiction of a particular highway agency and identify and prioritise those sites that have promise as sites for potential safety improvements. This screening is based on empirical Bayes estimates of the expected number of accidents by type and severity for each basic roadway element.

A road section consists of multiple segments of varying length. The homogeneous section approach treats each of the segments, whatever its length, independently and assesses whether the safety performance of that segment is of sufficient concern to be selected for detailed engineering studies. This is supplemented with a “peak searching” algorithm to identify the segments with highest accident frequency within a homogeneous section. Finally, a so called corridor approach is under development, where the road network is divided into corridors with a length of several miles.

For each specific location to be investigated, Safety Analyst will perform the following sequence of steps:

1. Prepare collision diagram template
2. Plot collision diagram
3. Identify accident patterns
4. Diagnose safety problems
5. Identify and select appropriate countermeasures

To help diagnose factors contributing to accidents, Safety Analyst asks a number of diagnostic questions. Each diagnostic question is framed to lead to a diagnosis and each diagnosis is framed to lead to a countermeasure. The diagnostic questions are intended to cover typical accident scenarios, rather than rare and unusual situations. The output of the office investigation diagnosis stage will be in the form of an interim report comprising all assembled information, such as:

– Collision diagram with all characteristics to be taken to the site if that investigation will take place
– List of accident patterns to be diagnosed, annotated with the season and time of the week and of the day, if any, that the accidents are most prevalent
– List of questions about the site that could not be answered in the office
– List of initial diagnosis
– List of potential countermeasures to be considered in the field

Following a field visit to each site, a final proposal for countermeasures is developed. Countermeasure selection involves multiple technical and budgetary considerations that are not appropriate for automated decision making.

For each concern identified through the diagnostic process, a list of potential countermeasures will be selected. If more than one concern has been identified at the site, more than one countermeasure list will be generated.

For further details about the method see www.safetyanalyst.org, where white papers about the four modules can be downloaded (Harwood et al. 2002, 2002a, 2002b, 2002c).

Comparison of current methods

Table 4.2 provides an overview of identification methods for hazardous road sections above in terms of the same or similar characteristics that were summarized for the methods for black spot identification in table 3.1.

Table 4.2. Overview of identification methods for hazardous road section in Denmark, Germany, Norway and the United States.

	Reference to popula-tion of sites	**Section length**	**Reference to normal level of safety**	**Recorded or expected number**	**Accident severity considered**	**Length of accident period**
Denmark	Yes	2-10 km	Yes, by means of category analysis	Recorded	Yes, by means of weights for 4 different categories of accident	5 years
Germany	Yes	3-10 km	Yes, by means of category analysis	Recorded	Yes, by means of weights for 3 different categories of accident	3 years
Norway	Yes	1 km, possible to merge adja-cent sections	Yes, by means of accident prediction models	Expected	Yes, by means of weights for 4 different categories of injured	8 years
USA	Yes	Several miles	Yes, by means of accident prediction models	Expected	Yes, possible to select to only the most severe accident	Optionally

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In contrast to BSM the road sections in NSM in all the reviewed countries are divided into clearly defined populations of roadway elements, whose members can be enumerated.

At the same time a reference to the normal level of safety for similar road sections is made in all four countries as it should be done. In Denmark and Germany it is done by use of relative simple category analysis, where the average number and severity of accidents are calculated, while it in Norway and the United States is done by use of more advanced prediction models, where the general expected number of accidents is estimated.

Denmark and Germany identify hazardous road sections by use of the recorded number of accidents and hence the random fluctuations are not taken into consideration in the identifying stage. In Norway and the United Stages, the identification is based on the expected number of accident by use of the empirical Bayes method.

The one kilometres road sections in Norway are often merged with adjacent section, when the sections have to be analysed and treated (Ragnøy and Elvik 2003). This means that all four countries in practice use varying section length between about two and 10 kilometres.

All the three European countries include accident severity in the identification of hazardous road section by applying weights to accidents at different levels of severity. The Danish and the German method use weighting of accidents, while the Norwegian use weighting of injured road users. All weights are based on average socioeconomic cost of injuries and in Denmark and Germany, the weights are also based on the average number of injured road users of different severity in the different severity categories. In the United States accident severity is partly include by the possibility to select to make an identification only based on the most severe accident as for example fatal accidents and accidents with seriously injured.

The length of the period used to identify hazardous road sections varies form three to eight years in the European countries. In the United States, the identification period is optional. Too few countries are reviewed with regard NSM to make a reasonable comparison between the lengths of identification periods used in BSM and NSM. However, in general you can say that the period used in NSM could be shorter than the period used in BSM, because normally there are more accidents on the long hazardous road sections than on the short black spots (Ogden 1996). On the other hand NSM is typical implemented in the most safe countries, which means that a longer period has to be used.

In general, it can be concluded that the identification methods in NSM typical are more advanced and closer to state-of-the-art approached and best practice guidelines than the methods for identifying black spots. This can maybe be explained by the fact that the methods for identifying hazardous road section are developed in countries with a long tradition for road safety management including BSM.

4.2 Classification of roadway elements

A central question in relation to application of NSM is how the road system should be divided into smaller road sections and how long these sections should be. This will be recommended in the following.

Note, that the following recommendations do not apply motorways, because the motorways differ quite much from the other roads with regard to both the traffic, the road design and the near surroundings. Typically motorways will be homogeneous on longer sections than the other roads, and therefore the section length sometimes advantageously can be longer than the section length recommended in the following.

4.2.1 State-of-the-art approach

Like identification of black spots hazardous road sections should also be identified by reference to a clearly defined population of different road sections for which the general expected number of accidents can be estimated.

4.2.2 Best practice guidelines

How the division should be done in practice is clarified under the description of the best practice guidelines and will be summarized in the following.

Constant or variable length

The road sections should have variable and not constant length. Variable length means that the road sections have different lengths for example between two and 10 kilometres. This is recommended because it offers the opportunity to ensure road sections that are more or less homogeneous with regard to parameters that have significant influence on the number of accidents. To make a model based identification of hazardous road sections as recommended in chapter 4.3 this is a necessary precondition.

Division of the road system

The road sections have to be homogeneous in order to make a model based identification, but how can the road system be divided into homogeneous sections in practice? Division can be done by relying on the following four principles:

1. Section based principle
2. Point based principle
3. Accident based principle
4. Combination

The two first principles can be characterized as road and traffic based division principles. In the first principle, the road system is divided into sections that are homogeneous with regard to selected traffic and road design parameters that have significant influence on the number of accidents.

The second principle is a point based principle, where intersections, towns or other “points” are used as division points.

The third principle is based on registered accidents in the identification period. Either there has to be a certain number of accidents on each road section or there has to be a uniform accident concentration or pattern on each road section.

The last principle is to combine the previously described principles. An obvious opportunity is to combine the first two principles. The two principles differ a lot from each other, but in practice, they will result in more or less the same division and can therefore advantageously be combined. The reason that the two principles approximately give the same result is that major changes in road design and traffic obviously coincide with larger intersections and towns.

To ensure reliable identifications and a potential for reducing the number of accidents the first two principles can be combined with the last principle that each road section has to have a certain number of accidents. Note that the principles about homogeneous road sections and a certain number of registered accidents often will be conflicting (Lynam et al. 2003, 2003a).

It is recommended that the road and traffic based division principles are used. The argument is that these principles can be used together with the model based identification method, where it is essential to have homogeneous road sections for the estimation of the general expected number of accidents. In addition, the advantage is that the principles more or less will result in the same division of the road system for different time periods, which makes it possible to compare the accident level for different time periods for each road section. Finally, the advantage of the point based principle is that it gives a rational, easy and natural division.

Length of road sections

The recommendation about how to divide the road system into road sections has relatively general character. In addition, the road systems vary much from country to country. This means that use of the same principle can result in road sections with varied length in different countries. Here it is recommended how long the section should be.

It is recommended that the section length should be in the interval between 2 and 10 kilometres, with an average section length around 5-6 kilometres. This corresponds roughly to the section length used in Denmark, Germany and Norway (Sørensen 2006, German Road and Transportation Research Association 2003, Ragnøy et al. 2002).

The argument for the minimum length is that the sections are not to be so short that NSM will resemble BSM. Additionally, the road sections are to have a certain length in order to make it possible to identify some general problems, and in order for general measures to have an effect. Finally, the sections have to have a certain length to avoid too great sensitivity to each accident (Renshaw and Everett 1980).

The argument for the maximum length is that the sections should not to be too long, as the consequence may be that shorter sub sections presenting problems will not be identified, as the many accidents on these sections "drown" in the overall average for the road section as a whole. Likewise, it may in the analysis stage be difficult to get an overview of very long sections, and long sections may also be very expensive to improve, if the given measures are to be carried out on the total length of the road section.

The interval from two to 10 kilometres can be considered as a large interval, but even so, it is recommended to make sure that it is possible to get homogenous sections. The large interval is also recommended, so the method can be adapted to different national conditions with regard to for example geographical conditions, infrastructure and density of intersections and towns. It can for example be assumed that the average section length is shorter in small countries than in large countries. Finally, the large interval offers the opportunity to choose section length depending on measures. If expensive measures are used short sections can be used, while long sections can be used when more inexpensive measures are used.

Note that it is impossible to get all road sections to be 100 % homogeneous, because it will result in too many very short road sections. In addition, it is probably impossible to divide the road system into sections that all have a length between 2 and 10 kilometres. Some will be a bit shorter than 2 kilometres and some will be a bit longer than 10 kilometres.

4.2.3 Implementation steps

The road system should be divided into sections that are homogeneous with regard to selected traffic and road design parameters, but how should these parameters be chosen?

Several of the following parameters are normally used:

- Road category, type, status or function
- Cross section including number of lanes, lane width, shoulder and the presence of bicycle lanes and side strips
- Possibility for oncoming traffic
- Speed limit
- Number and design of intersections and access roads

- Alignment including hills and bends
- Roadside buildings
- Traffic including AADT and type

The selection of parameters is influenced by the following conditions:

- The road sections should be homogeneous with regard to the parameters used as independent variable in the accident model or category analysis. This means that the road sections should be homogeneous with regard to parameters that have significant influence on the number of accidents. How to examine, whether a parameter has a significant influence on the number of accident is described in chapter 3.3.4.
- The selection of parameters depends on road and traffic data available, which can differ from country to country. To collect new data may be required, but this is very resource demanding.
- Parameters that not are expected to be changed in the treatment stage as for example road category, alignment and AADT can be used, while parameters that maybe have significant influence on the number of accidents but can be expected to be changed in the solution stage should not be used. This could for example be the number of access roads. This is important, so it is possible to distinguish between prerequisites and measures.

To make the division simple and not resource demanding it is recommend that the point based division method is used at first, where after it is controlled if the defined road sections are homogeneous.

The point based principle is based on intersections, towns or other “points” that are used as division points. Intersections will typically be defined as larger intersections to ensure that the sections between will get a minimum length. Larger intersections can be defined by relying on the following principles:

- *Road category or road authority:* Larger intersections are defined as crossings where intersecting roads belongs to a certain road category or road authority.
- *Traffic:* Larger intersections are defined as crossings where intersecting roads have a certain AADT as for example 500 vehicles per day.
- *Design:* Larger intersections are defined as intersections with a certain design or regulation as for example roundabouts or signal control.

Division by use of towns as divisions “points” is primarily relevant if the NSM only focuses on rural areas. Like for intersections it can also be discussed and defined what towns should be used as division points. To define a “division town” following parameters can be used:

- The length of the section in the town
- Number of buildings or houses in the town
- Changing of road design including speed limit
- Road sign with town and the character of the sign

4.3 Identification principles and criteria

In following it is summarized how hazardous road sections should be identified, and what should be done to implement this recommendation.

4.3.1 State-of-the-art approach

The state-of-the-art approach for NSM with regard to identification principle is the same as for BSM. This means that hazardous road sections should be identified in terms of the expected number of accidents estimated by using the empirical Bayes method.

The recommended identification criterion is also the same for NSM and BSM. Thus, hazardous road sections should be identified as road sections that have a higher expected number of accidents than the normal expected number on similar road sections due to specifically local and section based accident and injury factors.

However, there is one difference between the identification criterion for black spots and hazardous road sections. Accident severity should not be a part of the black spot identification itself, whereas it should be an integrated part of the identification of hazardous road sections. The argument is that longer sections with more accidents permit a more meaningful consideration of accident severity than short sections and intersections with fewer accidents.

The best practice guidelines describe how accident severity should be included systematically and completely as an integrated part of the identification stage of NSM.

4.3.2 Best practice guidelines

The state-of-the-art approach for BSM and NSM with regard to identification principle and criterion is the same. The recommendation with regard to best practice guidelines will thus also be the same.

Firstly, this means that identification of hazardous roads should be done by more or less advanced model based methods like identification of black spots. In chapter 3.3.3 it is clarified what a model based identification method is, and why this should be used as best practice guidelines.

Secondly, the hazardous road sections should be identified as the sections with the largest safety potential. The safety potential is calculated as the absolute difference between the registered and the general expected or average number of accidents, and thus indicates the obtainable reduction of accidents, if the road section in question after treatment reaches a general expected or average level of accidents. In chapter 3.4.2 it is clarified why this criterion should be used rather than the so called ratio criterion. In addition, it is described how the specific size of the identification criterion can be chosen.

Severity

As described, accident severity should be an integrated part of the identification of hazardous road sections. This can be done in several ways, but it is recommended that:

- The criterion is based on accidents and not injured road users
- Severity is integrated by use of a weighting principle
- Accidents are weighted by the severity of the most severely injured road users in the accident
- The accidents are divided into about three severity categories with different weights
- Weights for the different severity categories are calculated by use of the monetary valuations and the average number of injured road users of different severity in the different severity categories

The argument for using accidents rather than injured road users is that a identification based on injured road users can give misleading results with regard to identifying road sections with deficiencies and faults in the road design and the surroundings that can be a risk factor. The reason is that the number of injured road user can be a result of parameters that have nothing to do with the road design such as number of passengers, deficient use of seat belts or helmets, characteristics of involved persons such as age and characteristics of involved vehicles.

Severity should be integrated by use of a weighting principle, because it offers the opportunity to include all accidents in the identification. In other words, both number and severity of registered accidents are taken into consideration, which is to prefer (Taylor and Thompson 1977, Ogden 1996, Overgaard Madsen 2005).

The following six different weighting principles can be identified:

1. Same weight for all accidents
2. Only the most severe accidents included
3. Weighting by number of vehicles
4. Weighting by accident type
5. Weighting by injured road users
6. Combination

The four last principles are most relevant. Among these, the weighting should be based on the most severely injured road users in the accident rather than weighting by accident type or number of vehicles. The argument for this weighting principle is that it offers the possibility to be included in a model based identification, which is not immediately possible for the other principles. In addition, the principle is considered as easy to understand among people working with BSM and NSM (Sørensen 2006).

It is recommended that the accidents be divided into about three severity categories. This is assumed to give the best balance between getting a varied, a reliable and a practical division. Depending on accident level, accident data and policy the division can be done in the following two ways:

1. Accidents with killed and seriously injured
2. Accidents with slightly injured
3. Accidents with property damage

1. Fatal accidents
2. Accidents with seriously injured
3. Accidents with slightly injured

If possible is the first method recommendable because fatal accidents and seriously accidents are merged, whereby the problem of assigning a high weight to maybe random fatal accidents is eliminated. Likewise, it is very difficult for many countries to make a reliable estimate of a general expected number of fatal accidents, because it is a rare event, and an estimate is necessary to be able to develop a model based or category based identification of black spots or hazardous road sections.

The weights for the different severity categories can be determined in the two following methods:

1. *Cost of injuries:* The weights are calculated with basis in the socioeconomic cost of injuries, which is the average cost of accidents or injured road users of different severity, which have been calculated in several countries.
2. *Arbitrary:* The weights are decided arbitrarily with basis in for example political goals to focus on certain severity categories in the safety work.

It is recommended that the weights for the different severity categories are calculated by the first method, i.e. use of the monetary valuations and the average number of injured road users of different severity in the different severity categories. This is similar to the method described in German Road and Transportation Research Association (2003) and Sørensen (2006). The argument for the weighting by use of monetary valuations is that it is a more objective and professional method than the arbitrary decision, which can be very biased and political.

4.3.3 Implementation steps

Chapter 3.3.4 and 3.4.3 describes the implementation steps for at model based identification method for black spots, where the savings potential is used as identification criterion. These steps are the same for implementation of the recommended method for identification of hazardous road sections.

However, due to the integration of accident severity in the identification itself some supplementary steps have to be added.

Firstly, it is not enough to make one accident model. It is necessary to make an accident model for each of the three severity categories. The development of such models follows the same steps as described for estimation of a model for all accidents.

Secondly, it is necessary to collect information about the mean costs for traffic accidents or injured road users, or make an estimate of these, if this information is not available. As described before, this estimation is very complicated and will not be treated in this report.

The mean costs are in some case only calculated as mean costs for injured road users. If that the case, the mean number of injured road user of different severity has to be calculated for each accident severity category. These numbers can maybe differ from region to region. If that is the case, the numbers should be estimated for each region as it is done in Germany (German Road and Transportation Research Association 2003).

4.4 Accident analysis

This section describes how hazardous road sections should be analyzed, and what should be done to implement this recommendation.

4.4.1 State-of-the-art approach

The state-of-the-art approach for NSM and BSM is the same with regard to the analysis stage.

This means that the accident analysis should be performed in two stages. The first stage is, by means of detailed examination of accidents, to suggest hypotheses regarding risk factors that may have contributed to the accidents. Binomial tests should be applied in this stage to determine the probability that a dominant pattern of accidents is the result of chance only.

The second stage is to test the hypotheses. This can be done by means of a double blind comparison of the incidence of risk factors at each hazardous road and a comparison road section with a good safety record.

In chapter 3.5.1 you see an example on this analysis procedure for a black spot.

4.4.2 Best practice guidelines

As described in chapter 4.1.2 BSM and NSM differ from each other among others with regard to length of locations and overall philosophy for the work.

Black spots normally have a length of up to 0.5 kilometres, while hazardous road sections according to the recommendations have a length of between 2 and 10 kilometres. This means that there is a risk that local accident patterns and peaks on long road sections are not identified if only the normal black spot analyses are used, because the problem will “drown” in the average for the whole section (Hauer et al. 2002 and Sørensen 2007).

The difference between BSM and NSM with regard to overall philosophy is that BSM has a reactive nature, while NSM typically has both a reactive and proactive nature. This means that the analysis stage in NSM not only should include analysis based on the registered accidents as in BSM, but also should include a more general road examination or inspection and an assessment of the possibility of making some standard improvements on the given road section (Sørensen 2006, 2006a).

In general terms the best practice guidelines for the analysis stage are the same for NSM as for BSM, but the differences between BSN and NSM means that there are some exceptions. These are clarified in the following.

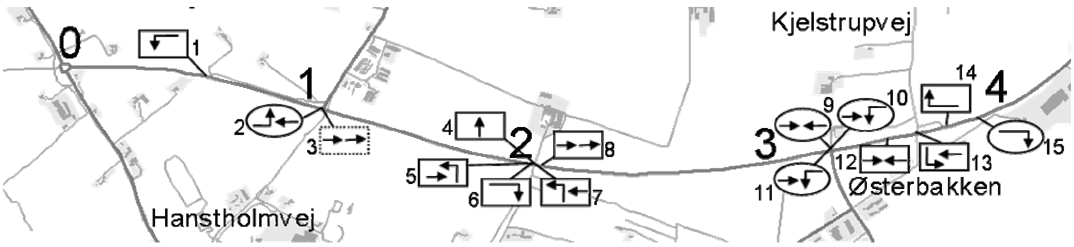
Accident analysis

To avoid the problem that some local accident patterns "drown" in the average for the whole section it is recommended to combine the general accident analysis and the traditional collision diagram into an extended collision diagram.

The extended collision diagram covers a traditional collision diagram, which has been amplified with information from the general accident analysis that normally not can be interpreted from the collision diagram.

Accident severity, accident situation, place and means of transportation can normally be read from a collision diagram. This should be supplemented with the most relevant information from the general analysis i.e. information about time (time of day, weekday, month and year), circumstances (weather, light, state of the roads etc.), drink driving, speed and maybe characterization of a person (sex, age, nationality, illness and use of safety features).

In the interest of clarity, which is the most central point in using a collision diagram it is recommend that the described data are added to the diagram by use of table besides the traditional collision diagram (Sørensen 2006, 2007a).



No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	03	03	03	02	03	04	04	04	02	02	04	02	03	03	03
Month	5	9	10	10	9	9	10	10	1	8	5	6	12	10	5
Day	7	1	5	6	2	1	3	1	4	5	5	7	6	6.	6
Hour	6	12	22	02	05	23	11	22	18	10	9	4	11	01	05
Type	012	410	198	031	660	032	650	140	241	410	410	241	660	011	023
Weather	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Rain	Rain	Rain	Dry	Dry	Rain	Dry
Road	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Wet	Wet	Wet	Dry	Wet	Wet	Wet
Light	L	L	D	D	D	D	L	D	D	L	L	L	L	L	D
Alcohol	Yes	Yes	Yes	Yes	-	Yes	-	-	-	-	-	-	-	-	-

Figure 4.1. A fictitious extended collision diagram for a 4 kilometre long road section with 15 accidents. Number on the map is kilometre, ellipse indicate accidents with injured and rectangle indicate accidents with property damage, L = light and D = dark (Sørensen 2007).

Figure 4.1 shows an example of an extended collision diagram. Here you for example see that it looks like that there maybe is some problems with wet road surface in the east end of the road section, some problem with accidents in dark in the middle of the road section and some problems with drink driving in the west end of the road section despite the fact that these problems can not be identified in the overall average for the road section.

Road inspection

The road inspection for a hazardous road section differs from a road inspection for a black spot in two ways. The first difference is the length. This means that it is recommendable only to make a road inspection of one hazardous road section per working day, while it is possible to inspect several black spots in one day (Sørensen 2006, 2007a).

The other difference is the difference in overall philosophy. This means that the road inspection both should concern traffic safety problems that have been a contributing factor in registered accidents and more general problems that by chance have not been a contributing factor in any accidents in the given accident period.

Based on an extensive literature survey and interviews Sørensen (2006, 2007a) has recommended how a road inspection of a hazardous road section should be made. This will also be recommended here. The recommendation is the following:

The road inspection should be made relatively formalized by use of a checklist. An example of a checklist developed for road inspection of hazardous roads is shown in table 4.3.

Table 4.3. Parameters, which should be included in the road inspection (Sørensen 2006).

Accident sites: Confirm or deny hypotheses from the analysis
Curves: Course, marking and road surface
Cross section: Road area, shoulder and central verge, bicycle lane and pavement as well as ditches and slopes
Intersections, driveways and crossings: Number, layout, channelization and regulation
Road surface: Friction, drainage, maintenance, edge drop off and high road verges
Message signing and marking: State and correctness
Crash fence and fixed objects: Masts, signs, trees, road stones, buildings etc.
Sight conditions: On the road section, from the byroads, optic guidance, illumination and dazzling

The road inspection should be made by two persons, one being a traffic safety employee, and one an employee of the road administration authorities' operating or project department. The road inspection should be carried out by car, and at the sites posing problems the surveyors should stop to examine the localities more closely. The inspectors should drive through in each direction and from relevant side roads. The road inspection should not be made at a specific time and should not last longer than a working day.

4.4.3 Implementation steps

Chapter 3.5.3 describes the implementation steps for accident analysis of black spots. These steps are in overall terms the same for accident analysis of hazardous road sections. The steps are:

- Identification of road sections that are safer than the average
- Matching of each hazardous road section to a safe road section
- Supplemental data collection for analysis of the matched locations
- Establishment of a procedure for blinded analysis
- Calculation of the normal accident patterns if the best practice guidelines are used in place of the state-of-the-art approach

In addition, it should be considered how the extended collision diagram in practice should be done. Maybe a program or some examples or template should be made.

4.5 Evaluation of the treatment of hazardous road sections

The last stage of the work in NSM is the evaluation of the treatment of the identified and analysed hazardous road sections. How this should be done is summarized in the following.

4.5.1 State-of-the-art approach

Like the previous stages of the work, the state-of-the-art approach for NSM is the same as the described state-of-the-art approach for BSM.

This means that the evaluation of the effects of the treatment of the hazardous road sections should employ the empirical Bayes before-and-after design, which makes it possible to control for local changes in traffic volume, long term trends in accidents and regression-to-the-mean.

In chapter 3.6.1 you see an example of the use of the Empirical Bayes method in a before-and-after study.

4.5.2 Best practice guidelines

Best practice guidelines for evaluation are also the same for NSM as for BSM. Thus, it is recommended to make a before-after-study, which controls for long-term trends in the number of accidents, local changes in traffic volume and regression-to-the-mean by use of the correction factors C_{trend}, $C_{traffic}$ and C_{reg}.

As described in chapter 4.1.2 BSM and NSM differ from each other with regard to the overall philosophy for the work. BSM can be characterized as having a retrospective nature, while NSM can be characterized as having both a retrospective and a prospective nature. Studies on how measures with both retrospective and a prospective nature should be evaluated are very rare, and thus it is also recommended that such studies are made.

4.5.3 Implementation steps

To implement the state-of-the-art approach for before-and-after studies of treatment of hazardous road sections it is a necessary precondition that the empirical Bayes method for estimating the local expected number of accidents has been or are developed and used in the identification stage.

If that is not the case, it is not immediately possible to make such an evaluation, and the evaluation should be made according to the best practice guidelines. For implementing these guidelines, it is necessary to make the calculation of the correction factors C_{trend}, $C_{traffic}$ and C_{reg} possible. In chapter 3.6.2 and 3.6.3 it is clarified how the different correction factors are calculated.

4.6 Summary

With the exception of few references, no definition of hazardous road sections has been explicitly formulated. In this project, the following definition is used and recommended. A hazardous road section is any section that:

1. Has a higher expected number and severity of accidents,
2. Than other similar road sections,
3. As a result of local and section based accident and injury factors.

This means that the basic philosophy roughly is the same for NSM as for BSM. Nevertheless, there are some differences:

– NSM typically has both a reactive and a proactive nature, while BSM is solely reactive. NSM has a reactive nature because the identification is based on the traffic accident history. The more proactive nature you see in the stages of analysis and treatment because they typically are based on both accidents and general traffic safety problems and standard improvements.

– Accident severity should be an integrated part of the identification of hazardous road sections, which is not the case for black spot identification. The argument is that longer sections with more accidents permit a more meaningful consideration of accident severity.

NSM can like BSM be divided in 10 more or less independent stages as described in figure 1.1. This can also be summarized in the following three activities:

1. Definition and identification of hazardous road section
2. Analysis of accidents and risk factors, designed to identify factors contributing to accidents and propose treatments
3. Implementation and evaluation of treatments

4.6.1 State-of-the-art approach and best practice guidelines

Table 4.4 summarizes the characteristics of the state-of-the-art approach and the best practice guidelines for NSM.

Hazardous road sections should be identified by reference to 2-10 kilometres road sections that are homogeneous with regard to the parameters that have significant influence on the number of accidents and are used as independent variables in accident models. This makes it possible to estimate the general expected number of accidents by use of an accident model.

The identification should be made by a more or less advanced model based method like the black spot identification. Use of not accident based identification methods in NSM should also be examined.

Table 4.4. Characteristics of the state-of-the-art approach and the best practice guidelines for network safety management (NSM).

	State-of-the-art	Best practice
Classification of sites	– Dividing of road system into clearly defined sites	– Dividing of road system in 2-10 km homogeneous sections
Identification principle	– The empirical Bayes method	– Simple model based method – Use of not accident based method should be examined
Identification criterion	– Higher expected accident number than the normal number – Severity is included	– The absolute difference criterion – Predefined number or a certain share – Severity is integrated by weighting the severity categories according to monetary valuations
Analysis	– Binomial tests of accident patterns – Blinded matched pair comparison	– Extended collision diagram, general inspection, traffic and road analyses – Comparing with normal accident pattern – True/false assessment
Evaluation	– Empirical Bayes before-and-after design – Should always be made	– Before-after-study with correction for trends, traffic and regression – Should not always be made, it depends of data – Further research how to evaluate combined retro- and prospective treatment

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Hazardous road sections should be identified as sections that have a higher expected number of accidents than the normal expected number on similar road sections due to local and section based accident and injury factors. Like black spot identification, the absolute difference criterion should be used.

In contrast to BSM, accident severity should be an integrated part of the identification criterion. Severity should be integrated by weighting by use of monetary valuations and the average number of injured road users of a given severity in different severity categories.

The same accident analysis method as in BSM should be used. However, regarding best practice guidelines there is some small differences. Thus, results from the general accident analysis and the collision diagram should be combined into an extended collision diagram to identify local accident patterns that “drown” in the average for the whole road section. In addition, the road inspection should be more general than the inspection of black spots and thus concern accident locations and general problems.

For the present, the evaluation of the treatment should be done like evaluation of black spot treatment, but it should be examined how evaluation of combined retrospective and prospective treatment can be done in a better way.

4.6.2 Implementation steps

The implementation steps for NSM are almost the same as for BSM described in chapter 3.7.2 and illustrated in figure 3.8. However, there are some small supplements with regard to classification of roadway elements and inclusion of accident severity in the identification stage. This is summarized in the following.

Division of the road network

The road system should be divided into sections that are homogeneous with regard to selected traffic and road parameters. These parameters should be chosen as:

- Parameters that are used as independent variables in the accident model
- If possible already available parameters
- Parameters that not are expected to be changed in the treatment stage

To make the division simple and not resource demanding it is recommend that the point based division method be used at first, where after it is controlled if the defined road sections are homogeneous.

The point based principle is based on larger intersections, towns or other “points” that are used as division points. In this context, it has to be defined what a large intersection and a division town is. Large intersection could be defined based on information about road category, road authority, traffic or design. The definition of towns could be based on information on the section length in the town, number of buildings, changing of road design or speed limit or road signs.

Accident severity

To integrate accident severity in the identification itself it is necessary to make not one, but several accident models. Thus, an accident model for each of the recommended three severity categories should be estimated. The development of such models follows the same steps as described for estimation of a model for all accidents.

Secondly, it is necessary to collect information about the mean costs for traffic accidents or injured road users, or make an estimate of these, if this information is not available. The mean costs are in some case only calculated as mean costs for injured road users. If that is the case, the mean number of injured road user of different severity has to be calculated for each accident severity category.

5 Conclusions

The objective of this report is to summarize state-of-the-art approaches and best practice guidelines for black spot management (BSM) and network safety management (NSM) described by Elvik (2007) and Sørensen (2007) and describe the necessary steps to implement the guidelines. This chapter summarizes the findings. In addition, some aspects about maintenance and updating of data and methods are discussed.

5.1 State-of-the-art, best practice and implementation

Table 5.1 summarizes the overall characteristics of the state-of-the-art approach and the best practice guidelines for BSM and NSM and what should be done to implement these recommendations.

Classification of roadway elements

Black spots should be identified by reference to a clearly defined population of roadway elements as for example curves, bridges or four-leg junctions, while hazardous road sections should be identified by reference to 2-10 kilometres homogeneous road sections. This makes it possible to estimate the general expected number of accidents by use of an accident model.

To make the division of the road system into clearly defined populations of roadway elements and homogeneous road sections it is necessary that the road authorities collect data about traffic volume, road design and the surrounding environment. These data have to be unambiguously located on the road network by use of for example stationing along all roads in the road network. In addition, the data have to be immediately interoperable with each other and the accident data collected by the police, so that it is possible in the identification stage to make an analysis of the correlation between the different data.

Identification principles

The identification of both black spots and hazardous road sections should rely on a more or less advanced model based method, ideally speaking the empirical Bayes method. The argument for this is that model based methods are the best to make reliable identification of sites with local risk factors related to road design and traffic control, because systematic variation and partially random fluctuations are taken into consideration.

Depending of how advanced the accident model is the development of such a model consists of different steps. The first step is to decide what the model should be used for and if the model should be used for state-of-the-art or best practice identification. The second and third steps are to select possible dependent and independent variables in the model and collect data about these variables. The fourth and fifth steps are to chose method for estimation and make the estimation based on the work in the previous four steps. The sixth step is to evaluate the models ability to explain and estimate the systematic variation in the accident counts. The final step is to make an empirical estimation of the expected number of accidents on each location.

Table 5.1. State-of-the-art approach (SOTA), best practice guidelines (BPG) and implementation steps for black spot management (BSM) and network safety management (NSM). Parenthesis indicate that the point only concern SOTA, BPG, BSM or NSM.

	State-of-the-art	Best practice	Implementation
Classification of sites	– Dividing of road system into clearly defined sites	– Same as state-of-the-art (BSM) – Dividing of road system in homogeneous sections (NSM)	– Stationing – Collection of accident, traffic and road data – Dividing of road system in similar road elements (BSM) or 2-10 km road sections (NSM)

Identification principle	– The empirical Bayes method	– Simple model based method	– Accident model estimation:
			  – Objective and variables
			  – Data collection
			  – Estimation method
			  – Regression analysis
			  – Goodness of fit (SOTA)
			  – EB estimation (SOTA)
			– Including severity (NSM):
			  – Model estimation for each severity category
			  – Estimation of mean costs

Identification criterion	– Higher expected accident number than the normal expected number on similar sites – Severity is not included (BSM) – Severity is included (NSM)	– The absolute difference criterion – Predefined number or a certain share – Severity is integrated by weighting the severity categories according to monetary valuations (NSM)	

Analysis	– Binomial tests of accident patterns
	– Blinded matched pair comparison
		– General accident analysis, collision diagram, inspection, traffic and road analyses
		– Extended collision diagram (NSM)
		– Comparing with normal accident pattern
		– True/false assessment
			– Comparison with safe site (SOTA):
			  – Identify safe sites
			  – Match unsafe and safe sites
			  – Data collection
			  – Blinded analysis
			– Comparison with normal accident pattern (BPG)
			  – Estimate normal pattern
			  – Match unsafe site and normal pattern

Evaluation	– Empirical Bayes before-and-after design – Should always be made	– Before-after-study with correction for trends, traffic and regression – Should not always be made, depends of data	– Assess if the evaluation should be made (BPG) – Estimate or chose correction factors (BPG)

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Identification criteria

Black spots and hazardous road sections should be identified as locations that have a higher expected number of accidents than the normal expected number on similar roadway elements due to specifically local risk factors. In the best practice guidelines, this is clarified. Thus, the identification criterion should either be a predefined number that the absolute difference between the expected and normal number of accidents (the savings potential) has to exceed or a certain percentage of the road network with the largest savings potential.

Due to more accidents, accident severity should be an integrated part of the identification criterion in the NSM, but not in the BSM. Severity should be integrated by weighting by use of monetary valuations and the average number of injured road users of a given severity in different severity categories.

To integrate the accident severity in the identification it is necessary to develop accident models for each of the recommended three severity categories. The development of such models follows the same steps as described for estimation of a model for all accidents. In addition, it is necessary to collect information or make an estimation of the mean costs for traffic accidents or injured road users.

Accident analysis

The state-of-the-art approach for accident analysis of both black spots and hazardous road sections consists of two stages. The first stage is, by means of detailed examination of accidents, to suggest hypotheses regarding risk factors that may have contributed to the accidents. The second stage is to test the hypotheses. This can be done by a double blind comparison of the each black or hazardous location and a safe location.

According to the best practice guidelines, the analysis stage should as a minimum consist of a general accident analysis, a collision diagram, a road inspection and relevant traffic and road analyses. In NSM results from the general accident analysis and the collision diagram should be combined into an extended collision diagram. The general accident analysis, the collision diagram and the extended collision diagram should be compared with the normal pattern of traffic accidents for the given type of location. Finally, an active and written assessment of whether the presumed black spot or hazardous road section is a true hazardous location or not should be made.

To make a comparison with a safe location or a normal accident pattern several steps have to be taken. The first step is to make an identification of safe locations. The procedure for this identification is the same as identification of black spots or hazardous road sections. The next step is to match each black spot or hazardous road section as closely as possible to a similar safe location. The third step is to make a supplemental collection of relevant data for analysis of the matched pair of locations. The last step is to make a procedure for the analysis so it is secured that the analysts do not know which site is black or hazardous and which site is safe.

Regarding the comparison with the normal accident pattern, it is necessary to make an estimation of the normal accident pattern and a procedure for matching the black spot or hazardous road section to a relevant pattern.

Evaluation of the treatment

Evaluation of the effects of the treatment should employ the empirical Bayes before-and-after design, because it controls for local changes in traffic volume, long term trends in accidents and regression-to-the-mean.

If it is not possible to make an empirical Bayes before-and-after evaluation, the evaluation should when possible be made as a simpler before-after-study controlling for long-term trends in the number of accidents, local changes in traffic volume and regression-to-the-mean by use of correction factors. A necessary implementation step is therefore to make a calculation of the correction factors C_{trend}, $C_{traffic}$ and $C_{reg.}$

5.2 Maintenance and updating

After the described methods have been implemented by the road authority it is very important that the data and methods are being maintained and updated. This is sometimes forgotten. Thus, an essential part of the implementation of the recommended methods is to make a procedure for maintenance. A typical problem is that there are no resources allotted for the maintaining and updating of the data and methods. A part of making the procedure for maintaining is therefore to secure money, time and personnel for the continuous maintaining and updating.

Data

Obviously, traffic accidents have to be registered continuously, but it is also important that information about traffic volume, road design and surrounding environment all the time are maintained and updated because both traffic and roads change over time for example as a result of traffic safety engineering.

It is important that this information is updated, because it is used as input to the road classification, the division of the road system into road sections, in the making of accident prediction models and in the comparison of hazardous locations and safe locations or the normal accident pattern.

When a location is changed, it is also important to record when the reconstruction is made, because this information should be used in the comparison of different locations, calculation of the normal accident pattern and possibly in a before-after evaluation.

Methods

The general safety level changes over time. Thus, the accident prediction models should also be reestimated continuously. This is very resource demanding. Therefore, it should not be done every year, but it is recommended that it be done in a three to five years cycle.

The updating is especially needed if the police recorded accidents in the accident database are supplemented with hospital recorded traffic accidents as recommended.

Finally, it is recommended that the model not just is maintained but also continuously improved, so the model and the use of the model all the time comes closer to the state-of-the-art approach at the top of the ladder.

The mean accident cost and the normal accident pattern should also be reestimated every few years, because these will also change over time.

6 Definitions and explanations

A very important part of the implementation of the described and recommended guidelines for black spot management (BSM) and network safety management (NSM) is that there is a full and common understanding of the terms used. The terms are normally explained the first time they are used in the report, but to help the reader some key definitions and some terms used in accident theory are also summarized in the following. The definitions and terms are listed alphabetically.

Accident model

An accident model consists of one or more mathematical equations for estimating the general expected number of accidents based on different characteristic features of the road design, the road environment and the traffic that have significant influence on the number of accidents.

Average number of accidents

The long-term mean number of accidents on a specific type of location per unit of time for a given interval, not referring to a specific exposure or a specific level of risk. The average number of accidents can be estimated by use of a category analysis. The average number of accidents do not shows the level of safety at a specific type of location with a given interval of traffic volume.

Black Spots

Black spots are any locations on the road network that have a higher expected number of accidents than other similar locations as a result of local risk factors.

Black spots are also referred to as hazardous road locations, accident prone locations, dangerous accident locations, problem locations, hot spots or sites with promise.

Black spot management (BSM)

BSM comprises the definition and identification of black spots, analysis of accidents and local risk factors at the black spots, proposing and implementation of treatments at the true black spots and evaluation of the treatments.

Category analysis

A simple accident model, where the set of accident, road and traffic data are divided into some predefined categories, and for each of these categories, the average number of accidents is calculated. The difference between an accident model and a category analysis is that in the accident model it is possible to describe correlation, where the independent variable is a continuous variable as it is the case for traffic volume. This is done by use of regression analysis where traffic volume is the regression variable.

Correct positives identified locations

Locations at which the local expected number of accidents exceeds the critical value selected for identification and the registered number of accidents exceeds the same critical value.

Correct negatives locations

Locations at which both the local expected and registered number of accidents are lower than the critical value selected for identification.

Empirical Bayes method

In the empirical Bayed method, the local expected number of accidents on a specific location is estimated as a weighted mean of the registered number of accidents at the location and the general expected number of accidents for similar sites estimated by accident models.

Expected or local expected number of accidents

The long-term mean number of accidents at a specific location per unit of time for a given amount of exposure and a constant level of risk. The expected number of accidents cannot be observed, but must always be estimated for example by use of the Empirical Bayes method. The estimated expected number of accidents shows the level of safety at the specific location.

Explained systematic variation in accident counts

The part of the systematic variation that is possible to explain by means of an accident model.

False negatives locations

Locations at which the local expected number of accidents exceeds the critical value selected for identification, but the registered number of accidents does not, due to random variation.

False positives identified locations

Locations at which the local expected number of accidents does not exceed the critical value selected for identification, but the registered number of accidents does exceed this value as a result of random variation.

Hazardous road sections

Hazardous road sections is any section on the road network that has a higher expected number and severity of accidents than other similar road sections as a result of local and section based accident and injury factors.

Hazardous road sections are also referred to as dangerous roads, problem roads, grey or red road sections, accident prone locations, one star roads, roads for safety investigation, roads with safety potential or promising roads.

Normal or general expected number of accidents

The long-term mean number of accidents on a specific type of location per unit of time for a given amount of exposure and a constant level of risk. The normal number of accidents can be estimated by use of accident models. The estimated normal number of accidents does not show the level of safety at a specific location, but the level of safety at a specific type of location.

Registered or recorded number of accidents

The number of accidents that has been reported at a certain location during a certain period. Due to random variation in the accident count, the recorded number is not always a good estimator of the expected number. Note that the recorded number normally is not the same as the true number, because of incomplete reporting.

Safety analysis of road networks or network safety management (NSM)

NSM comprises the definition and identification of hazardous road sections, analysis of accidents and local and section based accident and injury factors at the hazardous road sections, proposing and implementation of treatments at the true hazardous road sections and evaluation of the treatments.

Random variation in accident counts

The part of the total variation in accident count that due to the stochastic nature of the accidents is random. The random variation can also be explained as the variation in the recorded number of accidents around a given expected number of accidents.

Systematic variation in accident counts

The part of the total variation in accident count that are related to characteristic features of the drivers, the road design, the road environment and the traffic that have significant influence on the number of accidents. The systematic variation can also be explained as the variation in the expected number of accidents. The systematic variation is normally decomposed into explained and unexplained systematic variation.

Total variation in accident counts

The sum of random variation, unexplained systematic variation and explained systematic variation.

Unexplained systematic variation in accident counts

The part of the systematic variation that is not possible to explain according to an accident model due to for example inadequate data about the parameter.

Regression to the mean

Regression to the mean describes the fact that abnormally high number of accidents in one period will go down in the next period. In other words, it will regress towards the mean. Likewise, an abnormally low number of accidents in one period will go up in the next period. This can seriously bias the identification of black spots and hazardous road sections and before-and-after studies of road safety measures, if it is not taken into consideration. The empirical Bayes method can be used to control for regression to the mean.

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Institute of Transport Economics
Norwegian Centre for Transport Research

- carries out research for the benefit of society and industry
- has a research staff of around 70 highly qualified staff working in various areas of transport research
- co-operates with a number of organisations, research institutes and universities in Norway and in other countries
- carries out high quality research and assessment projects within topics such as traffic safety, public transport, the environment, travel behaviour, tourism, planning, decision-making processes, transport economics, and freight
- publishes research findings in the Centre's own report series, on the Internet, in the periodical "Samferdsel", as well as in national and international scientific journals and publications
- participates in the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) located near the University of Oslo