Discussion paper on Technical Justification for Network-Wide Road Assessment, “black spot”, route safety and network-wide road assessment

The report consists of an overall review of the different road risk assessment approaches, focusing specifically on “black spot”, route safety and network-wide road assessment, the techniques by which these approaches are implemented, as well as the primary principles and features of each approach.

On higher order road networks (such as the TEN-T, or national strategic roads, a proactive road assessment approach is recommended in accordance with other international guidance every 5 years. These relatively short networks carry such high volumes of traffic that this thorough approach along with an annual blackspot surveillance programme, is commensurate with the level of investment necessary. This allows various investment package scenarios to be modelled at a network wide level, allows the setting of (and monitoring against) road safety infrastructure performance metrics (as proposed by the WHO), and tracking and modelling of progress towards short term casualty reduction goals and longer term road safety ambitions (e.g. towards zero road deaths by 2040 or 2050).

On lower order networks with roads carrying above 5000 AADT, a three-step approach is recommended:

- As initial step it is important to perform an iRAP Crash Risk Map of the network, where the higher risk or higher potential return routes will be identified.
- The second step, according to the available resources, focuses on the most critical routes. The route assessment may be performed through iRAP Star Rating which provides detailed information about risk along the routes, an estimation of where fatal and serious injuries are likely to occur in the future and an initial Safer Roads Investment Plan.
- In the third step, development of a user defined investment plan (UDIP) is required and this may be focused where the greatest concentration of fatal and serious injuries are expected, where risk is high and where countermeasures show initial good returns in the iRAP model. It is important to apply local knowledge and engineering judgement to the iRAP model recommendations to ensure that the UDIP is practicable and appropriate to local conditions and practice. Since this step is the most resource consuming, it is of the decision makers’ benefit to assign it only where the interventions are likely to offer the highest Benefit to Cost Ratio.

So, to upgrade the road safety performance of a network, a top-down approach should be followed, narrowing the area of application, from a network to a road section level through well documented and worldwide accepted techniques.

The full report was coordinated and prepared by RSI Panos Mylonas within the framework of the EC CEF SLAIN project INEA/CEF/TRAN/M2018/179967 and a detailed report is available upon request.
There is no standard or official definition assigned to the term of a black spot. Nevertheless, from a theoretical point of view, a black spot is considered to be any location on the road network that has a higher expected number of crashes than other similar locations, as a result of local risk factors. Typically, black spots refer to specific roadway elements, such as intersections and curves, covering a road component no longer than 500 metres.

In general, a black spot is considered to be a site that has a high number of recorded crashes during a specific period. This definition implies that black spots cannot be profoundly identified without any reference to the normal level of safety. Some of the currently engaged definitions of black spots in European countries make an explicit reference to the normal level of safety, but this is not the norm. References to the normal level of safety are generally made by comparing the number of crashes at sites documented as black spots with the number of crashes expected for similar sites, typically estimated by means of crash prediction models.

In addition, some definitions of black spots take crash severity into account, while others do not. If crash severity is considered, there is no standard way of doing so. Thus, two alternative approaches could be identified. The first approach is to set a more rigid critical value for the number of fatal or serious injury crashes than for slight injury or damage only crashes, when identifying high risk sites. The second approach is to apply weights to crashes at different levels of severity and predefine the value of a critical indicator which should be exceeded in order to define a specific site as black. According to the above described approach, a single road location is named as a black spot and is regarded as a hazardous site, when there is an increased probability of crashes happening, particularly severe or fatal crashes.

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. Black spots are also referred to as ‘hazardous road locations’, ‘crash prone locations’, ‘dangerous crash sites’, ‘hot spots’ or ‘high risk sites’.

**Identification methods**

Black spot analysis has a long tradition in traffic engineering and still finds application in the road safety assessment process, in several countries of the European Union. The main argument behind this fact is that it is still regarded as a vital part of the site traffic safety work done by the road administration authorities. Since the 1950s and through the years, there is a set of methods and techniques that have been developed in order to detect hazardous sites. In general, identification methods may be disaggregated into crash based and non-crash-based methods.

Furthermore, the crash-based methods can be divided into numerical and statistical techniques. In contrast, the non-crash-based methods are analysed into observational techniques. In addition, site-related crash and GIS techniques are situated among numerical and statistical techniques. Finally, the diverse methods may be combined in several ways.

**Crash based methods**

The crash-based methods rely on data from the official crash statistics.

**Numerical techniques**

Concerning the numerical or non-model-based techniques, these techniques constitute elementary methods of determining hazardous locations and rely on plain comparison of selected constant values. The numerical methods define the period and specific locations, on which there is a high frequency of crashes. Apparently, these techniques do not take random fluctuation in crash counts generation into consideration. The random fluctuation in crash counts is explicated as the variation in the recorded number of crashes around a given expected number of crashes. On the opposite, non-model based methods are quite simple in use and do not require advanced scientific expertise.

Numerical techniques are further disaggregated into the crash count and crash rate calculation techniques, as in the following.

**Crash Count**

The ‘Crash Count’ technique suggests the simplest and fastest method for the determination and selection of high-risk sites. The process behind this technique is the following. Initially, the total of traffic crashes regarding a specific time period is recorded and then all crash sites are sorted in a descending order, according to the number crashes that have taken place. Subsequently, the locations with a number of crashes higher than a specified threshold-value are selected.

**Crash Rate**

The ‘Crash Rate’ numerical technique focuses on the calculation of the crash rate on a particular site. For the purposes of black spot analysis, crash rate is defined as the number of (injury or not) crashes per million vehicles approaching a site (e.g. intersection). The crash rate expresses the level of risk in a single location, due to the level of use of the road element, during a specific period.
Statistical techniques

As an alternative, model based, or statistical techniques are used in order to locate black spots. The rationale behind these techniques is that they take random variations in crash counts into consideration due to the stochastic nature of crashes. Thus, these methods use – in general – crash models or functions to estimate the local expected number of crashes at a specific location. The most significant statistical methods used are the Poisson analysis and Bayes Method, as detailed below.

Poisson Analysis

The Poisson analysis considers that traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a particular location can be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a quantity which is called the expected number of crashes.

The first crucial step towards the application of this method is to define a certain level of statistical confidence. Subsequently, it is recommended to estimate the expected number of crashes regarding the examined location. In this approach, the expected number of crashes (or Poisson distribution average) is equal to the average number of crashes of all locations under study, for the perceived period. After the above tasks have been accomplished, it is possible to calculate the critical number of crashes referring to the site under investigation. Finally, a single location is considered to be a black spot, if the recorded number of crashes exceeds the critical number of crashes (as calculated for a defined level of significance).

Bayes Method

In the Bayes method, the local expected number of crashes on a specific site is estimated as a weighted mean of the registered number of crashes at the location and the general expected number of crashes for similar sites estimated by crash models. In fact, the Bayes analysis relies on the traffic crashes record of a particular location in combination with the risk profile of other similar locations in order to define black spots. Therefore, locations with an extraordinary expected number of crashes are regarded as high-risk sites.

Site-related crash techniques

Site-related or site-specific crash techniques are located among both the numerical and statistical analysis techniques. The black spot determination process relies exclusively on site-related crashes through specific crash themes or types of crashes associated with road related risk factors whereby all interference from non-site-specific crashes is removed already in the identification stage. In this manner, the black spot analysis is, to some degree, already on track in the identification procedure. The main argument supporting this technique is that there will be a more effective traffic safety work as an outcome, compared with the traditional crash-based techniques.

However, site-related crash techniques incorporate some negative features. First of all, an essentially high number of crashes at a location compared with similar locations must indicate that there are local risk factors and it is thus redundant to tie the identification to road related crashes to detect sites with road related traffic safety problems. Furthermore, it can turn out to be a problem to limit the crash data, which already is limited in many countries. In addition, site-related crash recognition requires a relatively comprehensive identification process, which may demand quite a high amount of resources. Moreover, concentrating on particular themes and crash profiles could result in the failure to identify other traffic safety problems on the sites.

GIS techniques

GIS (Geographic Information System) based techniques are frequently used alongside other crash based techniques. In general, the principle is that the area under study is separated into squares, and the number of crashes in every square is counted. Black spots are then defined as the squares containing most crashes.

Non-crash based methods

As mentioned above, the crash-based methods depend on the official traffic crash statistics. However, due to severe under-reporting of crashes in many countries, a question emerges about the validity of the recorded data. Thus, there is an increased possibility that the registered statistics have a low and unbalanced coverage in comparison with the actual situation. This implies that there is a risk of focusing on some wrong locations and causing problems during the analysis. To avoid this problem, many efforts of developing and implementing non-crash based methods have been made.

Public authorities in many countries have made serious efforts to develop and publish specific non-crash based methods in the field of road safety assessment and, consequently, attempt to recognize hazardous sites. A significant non-crash based, observational technique that is used across the globe is the traffic conflicts technique.
Traditionally road crash statistics are used to assess the level of road safety and evaluate road safety programs. In some cases, though, the lack of valid and reliable crash records has hampered proper analyses. Moreover, traffic crash data are often not suitable for diagnosing safety problems at points of interest (e.g. intersections) or for evaluating the effectiveness of improvements. A considerable approach that overcomes these problems is the traffic conflicts technique which relies on observations of critical traffic situations for safety analysis.

In general, there is an increased possibility that traffic crashes occur at sites where a considerable number of evasive maneuvers and traffic violations are observed and recorded. Therefore, traffic conflict techniques enable transportation engineers to locate and investigate hazardous road sites without the need to obtain crash data. These techniques are the most developed indirect measure of traffic safety. The concept of these techniques is based upon the ability to identify the occurrence of near-crashes and therefore, offer a faster and, in many respects, a more representative way of estimating potential crash frequency and crash outcomes.

Although the above traffic conflict definitions and techniques have high face validity as indicators of safety hazards, it is still difficult to tie such events in a statistical fashion to traffic crashes. The main reason behind this statement is that traffic conflicts, as stochastic traffic events, vary quite markedly in number and rate from day to day even under nominally identical conditions, just as other traffic events such as crashes and turning volumes do. Furthermore, the assessment of conflicts engages an element of subjective judgement and therefore it is important to ensure that suitably skilled and experienced personnel undertake the analysis. Even though an individual could become extremely proficient and produce very repeatable results from day to day, it is operationally significant to recognize that the events themselves are not totally repeatable. As a consequence, traffic conflict techniques are mostly regarded as supplements, rather than replacements for crash data based methods. Finally, from the traffic conflict definition itself, it is concluded that traffic conflict techniques refer mostly to high risk spots rather than hazardous road sections.

Treatment Oriented Policies

Black spot analysis and single site investigations are the foundation of Road Safety Engineering. The identification of single high-risk sites and the investigation of crashes occurring at a single location lead to an understanding of the cause of the crashes.

Black spot Analysis Features

The main features underlying the rationale of black spot analysis are the following:

- Black spot analysis is associated with the definition and identification of hazardous road locations, typically referring to a single road element (e.g. intersection, curve, etc.).
- Black spot analysis constitutes a quite simplified approach of the road safety assessment process.
- The proposed countermeasures, following the completion of black spot analysis, are related to the upgrade of road safety on a low-scale (microscopic) level.
- Black spot analysis may resolve traffic safety issues concerning a single hazardous site, but other underestimated high risk locations may arise in the future.

Route Safety Assessment Definitions and Principles

Route safety assessment comprises the definition and identification of hazardous road sections along a route, analysis of crashes and section based risk factors at the hazardous road sections.

Similar to black spots, no international standard definition of hazardous road sections exists. It is also very difficult or maybe impossible to make a simple and short definition of hazardous road sections because it is necessary to consider many parameters in the formulation. However, definitions can indirectly be interpreted from the identification method.

Based on the explicitly formulated definitions, interpretation of current method and common understanding about route safety assessment, it is concluded that hazardous road sections most often are defined in the same way as black spots. This means that hazardous road sections may be defined as any section at which the site-specific expected number of crashes is higher than for similar sections, due to local and section based risk factors present at the site.

Nonetheless, this particular definition on hazardous road sections has been exposed to criticism. The main argument is that the definition and, subsequently, the identification method should not be based solely on site-specific crashes through specific crash themes or types of crashes associated with road related risk factors because this would remove all interference from non-site specific crashes already at the identification stage. In addition, this definition should not only include the number of crashes but also severity.

Based on the above analysis, the following definition of hazardous road sections is mostly used: a hazardous road
section is any section that has a higher expected number and severity of crashes than other similar road sections as a result of local and section based crash and injury factors. Hazardous road sections are also referred to as ‘dangerous segments’, ‘problem roads’, ‘grey’ or ‘red’ road sections, ‘crash prone locations’, ‘one-star roads’ or ‘roads for safety investigation’. The most common and frequently used term is hazardous road sections. The time period used to identify hazardous road segments varies from one year to five years. Typically, a period of three years is used.

**Division of the Road System**

The first crucial step towards the application of route safety assessment and the identification of hazardous road sections is the separation of the road system into discrete road segments. Thus, a basic question in relation to application of route safety assessment is how the road system should be separated into smaller road sections and how long these sections should be.

The division of the road system regularly depends on the method used to identify hazardous road sections. However, there are some common principles applied during the division process.

First of all, the road sections should have variable and not constant length. This is recommended because it offers the opportunity to ensure road sections that are more or less homogeneous with regard to parameters that have substantial influence on the number of crashes. Moreover, the road sections have to be homogeneous in order to obtain comparable results between the different segments. Therefore, division can be done by complying with the following four principles:

1. Section based principle
2. Point based principle
3. Crash based principle
4. Combination of the above

The first two principles are 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 essential influence on the number of crashes. The second principle is a point-based principle, where intersections, towns or other “points” are utilised as division points. The third principle is based on registered crashes in the study period. Either there has to be a certain number of crashes on each road section or there has to be a uniform crash concentration or pattern on each road section. Finally, the last principle is the combination of the above 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 some more or less similar division, since usually significant changes in road design and traffic apparently coincide with larger intersections and towns.

To ensure trustworthy identifications and a potential for efficiently reducing the number of crashes, the first two principles could be combined with the 3rd principle that each road segment is necessary to have a particular number of crashes. Note that the principles about homogeneous road sections and a certain number of registered crashes often will be conflicting.

The recommendation about how to divide the road system into road sections has relatively general character. Furthermore, road systems vary much from country to country, i.e., the use of the identical principle could result in road sections with varied length in different countries. Therefore, it is recommended that the road section length should be between 2 and 10 kilometres.

Note that it is impossible to get all road sections to be 100% homogeneous, because it would result in too many very short road sections. Moreover, it might be impossible for the road to be divided into sections that all have a length between 2 and 10 kilometres. Some would be a bit shorter than 2 kilometres and some could be a bit longer than 10 kilometres.

Of course, the above-mentioned section length intervals do not completely apply to motorway segments, which in general tend to be consistent in much longer sections (e.g. between intersections).

**Assessment Methods**

The procedures used to assess the road safety level along a route and identify hazardous road sections follow the same rationale as the pertinent methods used in black spot analysis. Hence, identification methods for hazardous road segments are separated into crash based and non-crash-based methods. The major difference between black spot identification methods and hazardous road section identification methods is located on the unit used to express risk, in each technique. Moreover, there are some supplementary identification techniques implemented in route safety assessment, while others used in black spot identification do not find application in the detection of hazardous road segments.

**Crash based methods**

The crash-based methods implemented to locate hazardous road sections may also be separated into numerical, statistical, site-related and GIS techniques. Regarding the numerical or non-model based techniques, these techniques are still considered to be the simplest methods of determining hazardous segments and rely on plain comparison of selected constant values.
Numerical techniques

Numerical techniques are further disaggregated into the crash density and crash rate calculation techniques.

Crash Density

The first technique suggests the simplest and fastest method for the detection of dangerous road segments. The process behind this technique is the following. Initially, the total of traffic crashes regarding a specific road section during a period is recorded and then all crash sites are sorted in a descending order, according to the crash density. Crash density is defined as the number of crashes per kilometre and is used as a risk measurement tool in order to make the comparison of road segments with different lengths possible. Subsequently, the segments with crash density higher than a specified threshold-value are selected and considered to be crash prone sections.

Crash Rate

For the purposes of route safety assessment, crash rate is defined as the number of (injury or not) crashes per million vehicles using a specific section of the examined route. The crash rate expresses the level of risk across a segment, due to the level of use of the segment, during a specific period. The identification stage follows the same process as the one of the crash density method.

Finally, a combination of the two above described methods is likely to be made. In this perspective, sections that recorded a crash density greater than a defined value (e.g. the average crash density among the population of sections), and had a crash rate higher than a critical value (e.g. the average crash rate) are classified as hazardous road sections.

Statistical techniques

In general, the statistical methods used to identify hazardous sections follow the same classification and rationale as the pertinent methods used in black spot analysis. However, there is one supplementary statistical method, which is applicable in the hazardous sections identification stage, named the Quality Control method.

Poisson Analysis

The Poisson analysis considers that traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a particular section can be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a quantity which is called the expected number of crashes, also known as the Poisson distribution average.

A road section is considered to be a hazardous section, if the recorded number of crashes exceeds the expected number of crashes (as calculated for a defined level of significance).

Quality Control

This statistical technique is based upon the division of the road facility into a number of road intervals. These road sections must be homogeneous, in terms of traffic volume referring to a particular period, as it is considered that the proper unit of risk is the crash rate, i.e. the number of crashes occurred at a certain section per million vehicle-kilometres travelled during a specific period. In addition, the road should be divided in a manner that each road interval contains approximately 14 to 25 crashes. The main argument behind this rationale is to eliminate the random variation in crash counts generation and, thus, reduce the interference of the stochastic nature of crashes.

With regard to the underlying statistical theory, it is assumed that each vehicle-kilometre is a sort of discrete entity and that the probability of a crash is the same for each vehicle-kilometre. It is also assumed that the vehicle-kilometres are statistically independent and that the number of traffic crashes follow the discrete distribution of Poisson. Thus, the probability of a certain number of crashes occurring in a specific number of vehicle-kilometres may be estimated. Basically, it describes the probability that any given number of crashes will occur in terms of this number and a quantity, which is called the expected number of crashes.

The fundamental idea underlying the method is the computation of upper and lower control limits, after the expected number of crashes has been estimated. The computation of upper and lower control limits relies on the use of a table of the Poisson distribution. From this table, upper and lower limits on number of crashes may be obtained. Dividing these by the number of vehicle-kilometres, the upper and lower limits for the observed crash rate may be calculated.

Finally, the comparison of the observed crash rate to the upper control limit is crucial. Thus, if the observed crash rate is higher than the upper control limit, it is concluded that the examined segment is “out of control”, which means that the actual number of crashes is not related to randomness (at a certain level of confidence).

Bayes Method

In the Bayes method, the local expected number of crashes on a particular section is estimated as a weighted mean of the registered number of crashes at the section and the general expected number of crashes for similar sections estimated by crash models. In fact, the Bayes analysis relies on the traffic crashes record of a particular segment in combination with the risk profile of other similar segments in order to define hazardous road sections. Therefore, sections with an extraordinary expected number of crashes are regarded as hazardous sections.
Site-related crash techniques

Site-related or site-specific crash techniques implemented during route safety assessment are similar to the ones applied at the black spot identification stage. The detection of hazardous sections relies solely on site-related crashes through specific crash themes or types of crashes associated with local and section related risk factors whereby all interference from non-site-specific crashes is removed already in the identification stage. In this manner, the route safety assessment is, to some degree, already on track in the identification procedure.

GIS techniques

GIS based techniques are frequently used alongside other crash based techniques. In general, the principle is that the area under investigation is separated into squares, and the number of crashes in every square is counted. Hazardous road sections are then defined as the squares containing most crashes. Yet, the use of these methods is questionable from a practical point of view. The key problem is that crashes are associated with areas, not road sections, thus it might be impossible to determine traffic and road design throughout the identification of hazardous road sections.

Non-crash based methods

The main benefit gained from the implementation of non-crash based methods in the route safety approach is that the level of risk on a particular road section or network can be defined without the need for detailed crash data, which is often the case in low-and middle-income countries where data quality is poor. The non-crash based methods implemented in route safety approach are further separated into quantitative and empirical techniques.

Quantitative techniques

The RAP protocols governed by iRAP and managed within Europe by EuroRAP include “EuroRAP Star Rating”. A remarkable non-crash based, quantitative technique used to assess route safety is the ‘Star Ratings’ technique developed by the iRAP.

The Road Assessment Programmes (RAP) method

Star Ratings show the inherent risk to the individual road user built into the assessed road network (per road user). The main objective of the RAP Star Rating is the improvement of road users’ safety by proposing cost-effective investment plans. The initial step for the implementation of the RAP method is the survey and subsequent recording of the infrastructure elements of a road network (or the conversion of existing asset data), which relate to road safety. The data recorded leads to the quantification of the safety that a road section provides to its users by calculating relative risk scores (Star Rating Scores). The Star Rating Score (SRS) is a measure of relative individual risk, which describes the level of safety built into the roads infrastructure for each road user type. The road user types currently included are vehicle occupants, motorcyclists, bicyclists and pedestrians. The Star Rating Scores are then classified into a Star Rating scale that expresses the safety capacity of a road section for each road user in a 5-Star scale that can be used as an international benchmark. This quantification aims to identify how the level of risk varies across a road network.

The assessment of road safety requires surveys of the road network sections and the assignment of a safety score to them. The inspection is conducted by visual observation and recording of the road infrastructure elements which are related directly, or not, to road safety and have a proven influence on the likelihood of a crash or its severity. The RAP assessments utilise inspection systems (varying from simple camera based solutions up to the inspection systems used for asset management inspections) to collect recorded georeferenced image/video data. The georeferenced image/video data can then be used to manually record the required road features at 100m intervals. It should be noted that as part of i.e. iRAP initiative, iRAP is working with a number of global and regional partners harness existing data sources and AI technologies to reduce the reliance on manual collection of the road features.

With regard to the Star Rating methodology, iRAP Star Rating is an objective measure of the likelihood of a road crash occurring and the severity of the outcome. The focus is on identifying and recording the road attributes which influence the most common and severe types of crash, based on scientific evidence-based research. Therefore, Star Ratings represent the risk of a fatal or serious injury to an individual road user.

In the Star Ratings approach, the level of risk to a road user on a particular road section can be defined without the need for detailed crash data.

Star Ratings may also be used to objectively quantify the level of risk associated with new road designs (where crash data is not available). They are also useful where low crash frequency limits the ability of crash analysis to influence performance monitoring and investment prioritization.
Road Safety Audit and Road Safety Inspection are considered to be the most effective non-crash based, empirical techniques to assess the level of safety along a route and identify hazardous routes or road sections, based on local and section related risk factors. The two terms are often combined and merge into one, simply known as Road Safety Audit. However, in this report, the two terms are separated and considered to be completely discrete entities.

**Road Safety Audit**

Road Safety Audit (RSA) is defined as a formal, independent assessment of the safety performance of a new road or proposed road design. The objective of road safety audit is to identify aspects of engineering interventions that could give rise to road safety problems and to suggest modifications that could improve road safety. It is important to note that road safety audit is not intended to be a technical check of compliance with design requirements. Highly trained auditors identify potential hazards and suggest recommended remedial treatments based on experience gained from crash investigation studies, road safety engineering schemes and associated research.

A RSA undertaken by competent, qualified auditors can provide a preventive approach regarding road safety issues already in the planning or design phases. Designs of current or planned roads or intersections are evaluated in terms of road safety, according to each auditor’s level of experience and perception. In this manner, a number of risk factors can be detected at a primary level of design and proper countermeasures (e.g. alterations to the road geometry) can be made before any actual problem emerges.

An Audit team works together on the audit to identify potential road safety problems and suggest suitable actions. In addition, the audit team is independent of the design team and often comprises members with different skills and abilities, a leader and several team members (e.g. may include law enforcement officer and/or client representative).

**Road Safety Inspection**

Road Safety Inspection (RSI) is a formal, independent assessment of the safety performance of an existing road that takes place in the field. Road Safety Inspection constitutes one of the most recognizable and valuable road safety evaluation techniques for roads already constructed and operated for years. This is also a major difference between Road Safety Inspection and Road Safety Audit.

The main benefit gained from Road Safety Inspection is that it is a process not affected by the crash record of a specific location and, thus, additional site-related risk factors may be identified during the inspection. Lack of crashes or a certain profile of crashes on a particular site does not mean that this specific site should not be further investigated. It might be only the outcome of mere randomness due to the stochastic nature of traffic crashes generation. Thus, the objective of Road Safety Inspection is also to locate potential risk factors that may expose road users to an unpredictable risk level and where possible to propose suitable treatments to eliminate or reduce risk.

**Treatment Oriented Policies**

There is a wide number of treatment-oriented policies implemented in road safety engineering in order to improve safety on a large-scale level, i.e., along a route or network. The most significant policies are the ones described below. Note that the design and implementation of these policies require that route or network crash problems have already been identified in the assessment process.

**Route Action Plan**

A standard route action plan, or route treatment includes all viable safety measures along a route (or network) optimised to reduce the highest number of fatalities and serious injuries. Plainly, a route action plan may be defined as the application of known remedies along a hazardous route or segment.

A route action plan may be customised to meet other requirements of the client or the context of the road assessment. There are many ways to customise route action plans. The most common approaches to customising route action plans include:

- To meet a defined budget or threshold for economic return. For example, where there is either a specified budget with which to undertake road safety upgrades, a minimum return or investment (in terms of benefit cost ratio or internal rate of return), or both.
- Ease of implementation. This is to assist road authorities to stage road upgrades in a way that accounts for construction lead times or budget appropriation. This way, upgrades that can be done immediately (such as delineation) are prioritised and more significant upgrades could be introduced to the planning pipeline for capital works.
- To support a maintenance program. This limits an Investment Plan to those things that may generally be undertaken as part of road maintenance and do not require capital works approval, planning or budget.
- To meet a Star Rating Target. A standard Star Rating target is 3-Star or better. A Star Rating target may be an official policy target or may be specified by the client for the specific road project.
Mass Action Plan

A mass action plan is defined as the application of a specific remedy to locations with a common crash problem. A mass action begins by having a measure that is known to reduce certain types of traffic crashes (e.g. the establishment of a central barrier prevents head-on crashes). Subsequently, the database is used to search for locations with a history of those crashes. Obviously, this procedure implies that the identification of risk factors along a crash prone route (or network) has been completed.

The practice works towards implementing the measure at the most suitable sites or locations. The remedy is known and is applied at locations with specific problems. A mass action plan might include work along hazardous road sections of a highway or at individual locations. Most highway agencies use a variety of mass action plans to improve the road network.

Area Wide Scheme

An area wide scheme is the most common concept of investigating crashes across a wider area, particularly urban residential areas. Area wide road safety engineering turns attention to residential areas where both the problem of crashes and the approach to crash reduction is quite different. They often involve different crash types and consequently routine blackspot and route-wide practices are less likely to be effective.

Route Safety Assessment Features

The main features of Route Safety Assessment are summarized in the following:

- Route Safety Assessment is associated with the definition and identification of hazardous road sections along a route, based or not on the crash statistics.
- Route Safety Assessment is based on the division of the road system into smaller consistent segments.
- In the route safety approach, a hazardous road section may consist of several black spots, but also any other location within the hazardous road section is regarded as a potential crash prone location and is further investigated in order to eliminate possible local or sectional risk factors.
- The proposed treatment oriented policies (e.g. route action plans), subsequent to the completion of route safety assessment, concentrate on the improvement of road safety along hazardous road sections.
- The proposed remedies (e.g. route action plans) comprise both responsive and anticipatory viable safety measures along a route optimised for the highest number of fatalities and serious injuries prevented.

Countermeasures proposed to resolve sectional traffic safety issues may initially seem like high cost solutions, but they may prove to be cost-effective resolutions on a long-term interval, as a considerable number of crashes may be prevented from occurring in locations without crash history, thus, minimizing the socio-economic impact.

Network-Wide Road Assessment

Definitions and Principles

Network-wide road assessment is defined as a systematic and proactive risk mapping procedure to assess the “in-built”, or inherent, safety of roads. Thus, network assessment is built on the philosophy of route safety assessment, where the risk of death and serious injury is estimated on individual road sections across a road network. Network assessment is based on the principle that different routes of a specific type are combined and shape a network.

The main objective of network assessment is to support national road safety strategies and add an extra layer of information alongside existing approaches. Therefore, network assessment enables the identification of the safest and most hazardous road sections within a region or country.

Assessment Methods

Network assessment methods follow the same classification, as the methods applied to assess the road safety level along a route and identify hazardous road sections. However, there is one supplementary method to the ones already illustrated, which assesses the crash risk level along a road network. This method is known as RAP Crash Risk Mapping and is described in the subsequent section.
Crash Risk Maps based on crash rates show the combined influence of behaviour, road infrastructure, vehicle and post-crash care. Various types of mapping are available:

- **Crash risk per vehicle km travelled** - Risk rate expressed as fatal and serious injury crashes per billion vehicle km
- **Crash density** - Risk rate expressed as the number of fatal and serious injury crashes per km per year
- **Crash risk by road type** - Risk rate expressed as fatal and serious injury crashes per billion vehicle km, relative to the average rate of roads with a similar traffic flow

Each of the above may be extended further to show risk ratings by crash types and road users where the availability and robustness of the data warrants doing so. They show the relative risk to an individual road-user (generally a vehicle occupant), or to the community as a whole, of being involved in a road crash involving fatal or serious injury.

Crash Risk Maps can improve the recognition among road-users that risk can significantly vary across road networks. In producing maps aimed at individual risk, it is therefore important to counter the common assumption that their purpose is to inform the road-user of how best to modify the route taken to minimise their likelihood of being involved in a crash.

Collective (or ‘community’) risk is used by road providers to reflect more broadly how the total risk to all road-users is distributed across a network. This information is crucial in determining how to spend available budgets effectively.

At the simplest level collective crash risk maps show the density, or total number, of crashes on a road over a given length. However, rates expressed in this way are largely influenced by the number of vehicles using a particular road section or link, given the positive correlation between fatal and serious crashes with traffic flow.

The RAP route structure is based on simple rules aimed at keeping as coherent a design as possible within any road section, while at the same time extending the section length far enough to give sufficient crash numbers to minimise year-on-year variation. Crash and traffic flow data are assigned to each section, typically compiled into three-year periods to give a statistically reliable estimate of risk. The assessment period can be extended where crash numbers are low.

Finally, the Crash Risk Mapping protocol converts both individual and collective risk into five coloured categories to visualise the level of risk across a network. These well-known colour coded maps show the risk to a road user of being killed or seriously injured.

Collective risk and individual risk are estimated for each road section. Collective (or ‘community’) risk demonstrates the crash density along a road section and is expressed as the number of fatal and serious crashes per kilometer per year. On the contrary, individual risk or crash risk per kilometer travelled is expressed as the number of fatal and serious crashes per billion kilometers travelled.

In summary, the standard procedure for producing RAP Crash Risk Mapping is illustrated in Figure below.

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**RAP Crash Risk Mapping**

iRAP provides the RAP protocol associated with network safety management, i.e. Crash Risk Mapping. The European Road Assessment Programme (EuroRAP) is an international not-for-profit organisation dedicated to saving lives through safer roads overcoming the application of the RAP protocols (including Crash Risk Mapping) within Europe. The Crash Risk Mapping protocol follows a route safety approach rather than focusing on high-risk single sites. In order to assess the level of risk across a road network and produce the data required for RAP Crash Risk Mapping analyses, crash and traffic flow data need to be assigned to individual road sections.

Crash Risk Mapping, by its very nature, relies on the use of existing crash and traffic flow data. As such, when published, some routes may already have had road safety improvements. Others may be more difficult to change, and, on these roads, it is particularly important for road users to be aware that they face higher risks than they might expect. Crash Risk Mapping should therefore be updated at regular intervals to ensure that it represents the most up-to-date picture.

Crash Risk Mapping protocol follows a route safety approach rather than focusing on high-risk single sites. In order to assess the level of risk across a road network and produce the data required for RAP Crash Risk Mapping analyses, crash and traffic flow data need to be assigned to individual road sections.

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Network safety management follows the network safety assessment procedure and incorporates proper treatment oriented policies in order to minimise risk across a road network. Furthermore, network safety management use acknowledged safety improvement programmes alongside other approaches, such as analysis at high-risk single sites. In general, network safety management advocates the use of economically viable mass action programmes (e.g. mass action plans) focusing on route safety as opposed to often lower cost improvements at spot locations.

Although network assessment may show that some sections carry higher risk than others, it does not necessarily mean that road authorities will and should regard these as the highest priority for improvement. Authorities rank roads for safety improvement, taking account of both the number of crashes likely to be saved through improvements and the cost of implementation. While not all roads can be managed to the same risk level, emphasis should be on keeping risk within acceptable boundaries. Discussion with authorities and police has shown that these bodies review high risk roads, comparing the output with road sections flagged by their own internal processes and in seeking to develop practical measures to reduce the risk to road users.

An alternative insight into network safety management is provided by the evaluation of crash rates related to road type averages. These demonstrate road sections with higher or lower risk after the expected variability between different road groups (i.e. motorways, dual carriageways, single carriageways, mixed carriageways) is taken into account. Benchmarking in this way involves highlighting roads that should be targeted, exploring why they fall short of the average safety standards for their road type, and assessing whether it is appropriate to apply countermeasures known to be effective on roads with similar design and usage characteristics.

### Network-Wide Road Assessment Features

The primary features of Network-Wide Road Assessment are summarized as follows:

- Network-wide road assessment is a systematic and proactive procedure aiming to assess the “in-built”, or inherent, safety of roads.
- Network assessment follows the philosophy of route safety assessment, where the risk of death and serious injury is estimated on individual road sections across a road network.
- Network assessment is a provides a supplementary layer of information alongside existing approaches (route safety assessment).

### Conclusions

The suggested countermeasures, following the black spot analysis, usually concern simple remedial measures that significantly reduce the problem on a local-basis level. By identifying and eliminating the features that make a site hazardous, road safety level can be considerably upgraded.

The main difference between black spot analysis and route safety assessment with regard to basic philosophy for the work is that black spot analysis has both a remedial and retrospective nature as black spot analysis but additionally a preventive and prospective nature. Route safety assessment has a remedial and retrospective nature because the identification stage relies on crash history. The more preventive and prospective nature is located in the subsequent analysis and improvement stages because they typically are based on crashes, general traffic safety issues and standard improvements. In this approach, the rationale is that remedial improvements on crash locations are spread out on the whole road section and thereby also gain a preventive and prospective nature.

Finally, a major difference between black spot analysis and route safety assessment is, by definition, the length of the road elements considered. Black spots typically have a length of up to 0.5 kilometres, whereas hazardous road sections have a length of between 2 and 10 kilometres.

The rationale for selecting and implementing the network safety approach relies on the following features of network assessment, which are also the comparative assets of this approach:

- Network assessment is regarded as a substantial tool for evaluating investment plans, thus, indicating locations where the largest return of investement – in terms of risk reduction – is expected.
- Network assessment, as a systematic procedure, supports performance tracking, a way of evaluating success and the effectiveness of investment in safer roads.
- Network safety management, which follows network assessment, advocates the use of financially viable mass action plans focusing on route safety as opposed often lower cost improvements at spot locations.
- Network assessment is utilized for the support of national road safety strategies and plans.

In addition, the proposed framework underlying the network assessment follows the Safe System approach. This approach is based on the principle that human beings can and will continue to make mistakes and that it is a shared responsibility of actors at all levels to ensure that road crashes do not lead to serious or fatal injuries. According to the Safe System approach, the safety of all parts of the system must be improved — roads and roadsides, speeds, vehicles and road use so that if one part fails, other parts will still protect those involved.
Road infrastructure will continue to be very much part of the network safety approach. Well-designed and properly maintained roads can reduce the probability of road traffic crashes, while ‘forgiving’ roads (roads laid out in an intelligent way to ensure that driving errors do not immediately have serious consequences) can reduce the severity of crashes that do happen.

In conclusion, the network safety approach is totally in compliance with international best practice. Currently, international best practice is developing long-term programmes with the goal of eliminating death on the roads. These ‘vision zero’ programmes are developing a ‘safe system’, in which the driver, vehicle, and road are seen as one combined system protecting all road users from serious harm.

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