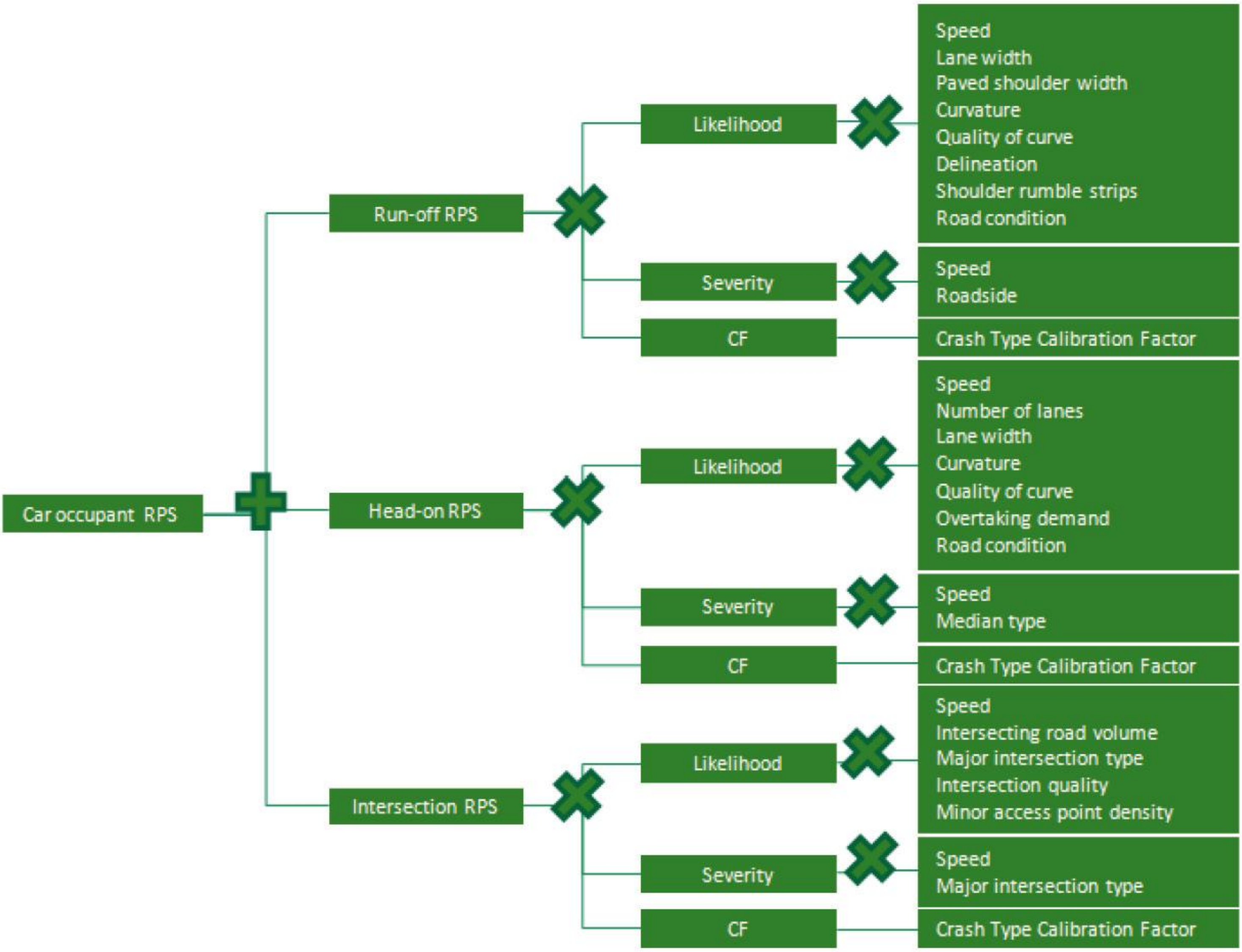
International Road Assessment Programme

DEVELOPMENT OF RISK MODELS FOR THE ROAD ASSESSMENT PROGRAMME



Development of Risk Models for the Road Assessment Programme

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About iRAP and EuroRAP

The International Road Assessment Programme (iRAP) is a charity dedicated to saving lives through safer roads.

iRAP works in partnership with government and non-government organisations to:

- inspect high-risk roads and develop Star Ratings and Safer Roads Investment Plans
- provide training, technology and support that will build and sustain national, regional and local capability
- track road safety performance so that funding agencies can assess the benefits of their investments.

Road Assessment Programmes (RAPs) are now active in more than 70 countries throughout Europe, Asia Pacific, North America. Latin America and Africa.

iRAP is financially supported by the FIA Foundation for the Automobile and Society and the Road Safety Fund. Projects receive support from the Global Road Safety Facility, automobile associations, regional development banks and donors.

National governments, automobile clubs and associations, charities, the motor industry and institutions such as the European Commission also support RAPs in the developed world and encourage the transfer of research and technology to iRAP. In addition, many individuals donate their time and expertise to support iRAP.

The European Road Assessment Programme – EuroRAP AISBL – is an international not-for-profit association (Association internationales sans but lucratif) registered in Belgium. Its members are motoring organisations, national and regional road authorities, and experts who have been elected because of the special contribution they have made to EuroRAP.

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To find out more about the programme, visit www.irap.org. You can also subscribe to 'WrapUp', the iRAP e-newsletter, by sending a message to icanhelp@irap.org.

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Preface

iRAP and EuroRAP are grateful of the contribution of David Lynam, Chief Research Scientist, TRL and to those in the ARRB Group, Midwest Research Institute and the then Swedish National Road Administration whose work led to the development of the models described here. By 2012, these EuroRAP and iRAP protocols, have been used, or are about to be used, in around 50 countries.

This paper, prepared in 2010, provides a retrospective of the development of the work and, in particular, on the original iRAP model, “Version 1.0”.

iRAP has a policy of continuous improvement and has benefited from the knowledge gained through the application of the original iRAP model in low- and middle-income countries. As a result, it has been possible to build on the pioneering work described here. The latest developments in iRAP’s work are presented at www.irap.org.

This report was produced by TRL under contract to iRAP. The methodologies and all the foreground intellectual property referred to in the report are the property of iRAP and EuroRAP. To ensure high quality and consistent application of the methodology, organisations wishing to use or reproduce the methodology are required to receive a formal licence issued by iRAP or a regional association such as EuroRAP, usRAP, AusRAP or kiwiRAP. Recipients undertake to support the ethos of consistency in the quality of applications and to assist continuous improvement. As a registered charity, iRAP provides unrestricted access to the methodologies for use around the world to help achieve its vision for a world free of high risk roads. To find out more about iRAP Membership visit http://www.irap.org/irap-membership.html.

Government agencies, local partners and consultants are encouraged to be trained in applying the iRAP Star Rating and investment protocols to ensure local ownership and understanding of the model and open procurement of iRAP assessments where required.

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Contents

Executive summary

During 2001, a process of risk rate mapping was developed by TRL for the European Road Assessment Programme (EuroRAP) to enable the risk of fatal and serious injury accidents occurring on different parts of the British primary road network to be compared. The definition of road sections and the use of risk rate as a measure of safety built on earlier work which TRL had done for the Highways Agency network. This process was subsequently applied to several European countries. As a second stage of risk comparison, a risk rating system was developed which ranked road sections according to their road design features. This process initially focussed heavily on the injury protection qualities of the road design, and was described as the "Road Protection Score" (RPS). This rating process was first used extensively in Sweden and Germany, but was subsequently applied in other European countries including the United Kingdom. The concepts pioneered by EuroRAP were adopted in Australia (as AusRAP), where the rating system was extended to include accident likelihood as well as injury protection, and have also been trialled in the United States (usRAP), and in New Zealand (KiwiRAP).

In 2006, under the International Road Assessment Programme (iRAP), the concept of an RPS rating process was further developed to enable it to be applied in low- to middle-income countries with the objective of developing cost-effective programmes of road safety countermeasures for those countries. To do this a model was developed which initially assessed the risk of severe accidents on each road section, rating this in a similar way to the RPS, and then used the risk values to estimate numbers of fatal and serious casualties and to predict the accident reductions and cost benefit ratios if potential countermeasure programmes were applied.

The risk model development for these programmes was led by TRL under contract to EuroRAP and iRAP, and with substantial input from the EuroRAP and iRAP members and partners, particularly the Swedish National Road Administration for the EuroRAP RPS process, and the Australian Road Research Board (ARRB Group) and Midwest Research Institute, Kansas, for the iRAP model.

This report describes the ideas behind the development of both risk models from the viewpoint of the TRL researcher leading the development process. It discusses the objectives of the initial EuroRAP rating system and the development of a risk framework to underpin the star ratings.

EuroRAP ratings only assessed the risk to car occupants, combining ratings for three main accident types – run-off accidents, median accidents and junction accidents. The report discusses the evidence that was collated by which to try to ensure that the ratings gave a reasonable representation of the risk of severe injury, and summarises the results of comparisons between the ratings and observed accident data on groups of roads in several countries to provide an indication of their validity.

The basis for extending these ideas within the iRAP model to meet the broader requirements of that programme is discussed. The iRAP models included more factors, and sub-models were included for motorcyclists, pedestrians and pedal cyclists as well as car occupants. The additional evidence used to decide risk factor values in these models is described.

The final part of the report suggests how the model results should be interpreted and used to improve network safety, discusses some of the limitations of the models and the potential to extend the rating model used in EuroRAP to align it closely with the iRAP model. The different potential use of ratings by consumers and road managers is highlighted, linking the results to current good practice and to ideas for Safe Systems.

Abstract

During 2001, a process of risk rate mapping was developed by TRL for the European Road Assessment Programme (EuroRAP) to enable the risk of fatal and serious injury accidents occurring on different parts of the British primary road network to be compared. As a second stage of risk comparison, a risk rating system was developed which ranked road sections according to their road design features. This process initially focussed heavily on the injury protection qualities of the road design, and was described as the "Road Protection Score" (RPS). In 2006, under the International Road Assessment Programme (iRAP), the concept of an RPS rating process was further developed to enable it to be applied in low- to middle-income countries with the objective of developing cost-effective programmes of road safety countermeasures for those countries. The risk model development for these programmes was led by TRL under contract to EuroRAP and iRAP, and with substantial input from the EuroRAP and iRAP members and partners, particularly the then Swedish National Road Administration for the EuroRAP RPS process, and the Australian Road Research Board (ARRB Group) and Midwest Research Institute, Kansas, for the iRAP model. This report describes the ideas behind the development of both risk models from the viewpoint of the TRL researcher leading the development process. It discusses the evidence on which the risk models were based and the comparison of their outputs with observed accident data, and suggests how these outputs should be used.

1 Introduction

During 2001, a process of risk rate mapping was developed by TRL for the European Road Assessment Programme (EuroRAP) to enable the risk of fatal and serious injury accidents occurring on different parts of the British primary road network to be compared (TRL 2005). The definition of road sections and the use of risk rate as a measure of safety built on earlier work which TRL had done for the Highways Agency network. This process was subsequently applied to several European countries. As a second stage of risk comparison, a risk rating system was developed which ranked road sections according to their road design features. This process initially focussed heavily on the injury protection qualities of the road design, and was described as a "road protection score" (RPS). This rating process was first used extensively in Sweden and Germany, but has subsequently been applied in other European countries including the United Kingdom (Castle et al 2007). The concepts pioneered by EuroRAP were adopted in Australia (as AusRAP), where the rating system was extended to include accident likelihood as well as injury protection, and have also been trialled in the United States (usRAP), and in New Zealand (KiwiRAP).

In 2006, under the International Road Assessment Programme (iRAP), the concept of an RPS rating process was further developed to enable it to be applied in lo- to middle-income countries with the objective of developing cost-effective programmes of road safety countermeasures for those countries. To do this, a model was developed which initially assessed the risk of severe accidents on each road section, rating this in a similar way to the RPS, and then used the risk values to estimate numbers of fatal and serious casualties and to predict the accident reductions and cost benefit ratios if potential countermeasure programmes were applied.

The risk model development for these programmes was led by TRL with substantial input from the EuroRAP and iRAP members, particularly the Swedish National Road Administration for the EuroRAP RPS process, and the Australian Road Research Board (ARRB Group) and Midwest Research Institute, Kansas, for the iRAP model.

This report describes the ideas behind the development of both risk models from the viewpoint of the TRL researcher leading the development process. Section 2 describes the development of the initial EuroRAP rating system and Section 3 describes the development of the iRAP model. Section 4 suggests how the model results should be interpreted and used to improve network safety, discusses some of the limitations of the models and the potential to extend the rating model used in EuroRAP to align it closely with the iRAP model.

2 Rating process within European Road Assessment Programme

2.1 The definition and role of Rating Systems

EuroRAP requested that a rating system from 1 star to 4 stars be devised to describe the relative safety of different parts of the primary road system. Such a rating system is used in many other contexts, eg comparing standards of hotels and restaurants, and the group of motoring organisations that initiated EuroRAP had already used the concept for describing the quality of transport facilities (eg safety of road tunnels). This type of rating was seen primarily as providing information to consumers, and thereby encouraging facility providers to improve their standards.

The most relevant prior system on which to base EuroRAP was the European New Car Assessment Process (EuroNCAP) which rated the safety of common passenger car models. This initially used a four star rating system (subsequently extended to 5 star) and gave separate ratings for the protection provided to car occupants in the event of an impact, and for the protection provided to pedestrians if struck head-on by the car. For occupants the ratings were based on physical tests of the forces and decelerations on dummy occupants under different types of impacts at defined speeds, while for pedestrian protection, forces and decelerations were measured when the vehicle was struck with head and leg impactors.

The concept of physical testing is already applied to some aspects of road design (eg the performance of safety barriers) but an overall assessment of road safety requires a different approach. A twin assessment process was devised – first to rate the road in terms of its observed accident history, and second to rate the road directly in relation to its layout and the presence or absence of features likely to have a major influence on injury protection.

The first process (risk rate mapping) required dividing the network into road sections that were sufficiently long to provide a three year total of fatal and serious accidents that would be likely to give a robust estimate of the long term accident rate for the road when divided by the average total traffic flow for the road section. A total of 20 accidents per three years was targeted per rated length but some shorter road sections had to be used where road type or traffic flow changed more rapidly. The estimated rates were divided into five rate bands giving a good spread of rates over the British primary road network, which was the first network assessed. The process is described in more detail in Lynam (2005).

The second process is much more subjective as it requires the key features on which the rating is to be based to be identified and to be given a score reflecting their relative contribution to injury protection. A critical factor in this contribution is the speed at which the vehicle is travelling when an impact occurs.

Initially the rating system was seen as setting four levels of road design (one for each star rating) at a few selected speeds (Lynam et al 2003), but it was soon clear that to accommodate the wide range of designs and typical speed limits within different European countries, a consistent framework was needed that reflected the difference in risk between each combination of speed and design. This was achieved by establishing families of risk curves for each of three key accident types (Lynam et al, 2004), as described in Sections 2.2 and 2.3.

The existence of both observed accident data and safety ratings for common lengths of road provided the potential to calibrate the ratings, and establish the change in risk associated with each change in star rating. This has only been achieved to a limited extent to date, but initial analyses suggest roughly a doubling of risk with each change in star banding with the current EuroRAP and AusRAP ratings. More detailed analyses are needed to show how consistent this is between different accident types and on different road types.

Linking ratings to accident rates in this way potentially makes the rating system much more widely usable than simply a consumer information aid. Road authorities can see what changes in design would be needed to improve safety ratings and the change in accident numbers that might be achieved as a result of this change in road design. Rating all roads within large networks enables discussion of the levels of safety appropriate across the whole road network (rather than simply considering action at a small number of higher risk sites) and the cost of changing safety levels. The structure of the rating systems which explicitly includes the interaction of vehicle design, road design, and road user behaviour also enables the appropriate contributions from each of these components to form part of this discussion. In the RAP assessments, roads are rated in terms of their protection when a five star car is being driven within the traffic law.

What ratings should be targeted, and what does 4 star mean? A 4 star rating in EuroRAP was given for those conditions where a collision was judged very unlikely to result in a fatal outcome. The availability of biomechanical data that had formed the basis of the EuroNCAP testing was extremely useful in identifying typical conditions that met this criterion, but there remained substantial subjectivity in the choices made. The same rating risk scale is used for all road types. Thus a motorway might always be expected to score more highly than a 2 lane road. But in practice what is required is an appropriate design for the speed at which traffic will use the road, and well-designed 2-lane roads can still achieve high ratings. However in economic terms, improvement of low flow 2-lane roads may often not be justified if current valuations of accident savings are used.

2.2 Basis for EuroRAP rating system

The version of the EuroRAP RPS described here (RPS1.0) provides a measure of how well the road layout and road infrastructure helps to protect car occupants from serious injury if a collision occurs.

If all other factors are consistent, the RPS scores should give a good indication of the relative numbers of killed and seriously injured casualties to expect on different road sections. But with the basic version of the RPS, the scores will not match KSI numbers where

- the likelihood of an accident occurring varies between roads of the same type
- those involved in the accident are not complying with the behavioural design “envelope” for the road ie being belted and being within legal speed and drink drive limits; inappropriate speeds within the limit might still be adopted, for example on bends
- there are a substantial number of accidents resulting in injuries to road users other than car occupants
- the car occupant accident pattern is dominated by types other than run-off, junction or frontal car to car impacts.

Although the RPS does not capture all aspects of risk it can potentially be a better indicator of the influence of road design on the risk of serious injury than total accident numbers because it highlights some of the risks arising directly from road design. It also provides a basis for assessing risk when accident data are not available – eg in the early life of a modified road section.

An injury accident results from a chain of events, starting with an initial event probably resulting from several factors, which leads to a dangerous situation. If action is not taken to avoid it, a crash will occur. The severity of injury of that crash will depend on the kinetic energy involved in the impact. The outcome can be modified by intervening at any point in this chain to reduce the kinetic energy to a tolerable level. The accident might be avoided completely, if there is early intervention, but this would need to target all the factors potentially giving rise to the dangerous situation. Intervention at the impact stage will not reduce the number of impacts, but will reduce the severity of injury whatever the initial factors giving rise to the dangerous situation.

The initial focus of the RPS primarily on injury protection is being extended by adding a risk element for the likelihood of accidents occurring (Section 4.7). However it will remain important still to be able to see the various parts of the RPS separately as they relate to different causes of risk and potentially imply different types of remedial measure. The RPS is also currently aimed at assessing main rural roads, and further work is needed to consider how the principles can be extended to urban roads.

The approach of assessing protection separately from other factors, and assessing protection separately for different road users, is in line with the philosophy adopted in car secondary safety assessment programmes (NCAP). This is important as it potentially allows the contribution to protection from the vehicle and the road to be compared in collisions where vehicles leave the road. Results from biomechanical research associated with occupant protection in car to car collisions also inform the levels of risk to be regarded as acceptable in collisions associated with road design deficiencies.

In both cases, the level of injury risk is strongly related to impact speed. Thus in NCAP testing, the test speed is set at defined levels and injury outcome criteria assessed against established thresholds. Road assessment does not reflect driving under controlled conditions, but evaluation can again be done against a defined speed level. The choice of an appropriate assessment speed is not clear cut as drivers should be adapting their speed to the hazards they meet. The posted speed limit for car traffic is used in EuroRAP, as this is the maximum speed that drivers can adopt and stay within the behavioural envelope defined by the assessment protocol. An exception may be made where the majority of traffic is travelling at a speed substantially above the posted limit.

As the level of risk is set as far as possible to be consistent with cars which have an occupant protection consistent with 4 stars on the NCAP scale, the road assessment also inherently assumes that risk will only be at a minimum if all vehicles using the road are of this standard. The car fleet is, over time, moving to this standard, but collisions involving other vehicles, for example HGVs, which do not result in the same low level of injury, will not be reflected in the current version of the RPS.

The assessment focuses on three areas of road design - treatment of roadsides, median separation of traffic flows, and design and frequency of junctions. These were chosen because they match accident types – single vehicles leaving the road, head-on collisions, and collisions at junctions – that make up about 75% of the total number of fatal and serious accidents on main rural roads (OECD,1999).

As part of the analysis of accident patterns, two further accident types were considered – accidents involving pedestrians and cyclists, which typically make up about 5%, on average, of accidents on these roads, and the remaining 20% of accidents, a large proportion of which are associated with rear end shunts. These two accident types are not included in the current assessment. Assessment of safety for vulnerable road users ideally needs to be done taking into account the usage of the road by these groups, which is not necessarily clear from road inspections, while the occurrence of rear shunts is likely to be more related to traffic management and design factors which affect traffic behaviour rather than to forgiving road design. These two aspects are therefore being considered separately.

The basic rationale for developing risk scores for use in the RPS is therefore a process of developing families of curves showing how car occupant injury risk varies with traffic speed and with different design changes. A family of curves is developed for each of the three areas of the road that are assessed. These represent the relative risk of a fatality occurring – based on the biomechanical understanding developed from the vehicle tests and knowledge of relative serious injury rates on roads with different design features.

Each curve starts with a risk of 1 at the speed at which NCAP results show impacts of the type being considered can be sustained with only low risk of a fatal injury. Thus risks of 1 are assumed at a speed of 70km/h for car to car head-on collisions (consistent with the 64km/h test speed for frontal impact) and for 50km/h for side impacts at junctions (the test speed for side impact vehicle tests). There is no vehicle test directly equivalent to head-on vehicle impact into an aggressive object after leaving the road; unit risk for road assessment in this case has been assumed at a speed of 60km/h, although it is noted that NCAP side impact pole tests are done at 29km/h.

The risk for well designed safety elements at the roadside or median is assumed to stay at a similar low level for speeds up to 120km/h. This reflects the fact that roadside and median restraints are required to operate effectively up to this speed. For junctions a similar assumption is made for designs with merging angles and merging lengths that enable vehicles to come together in the traffic stream without the risk of high angled side impacts.

The two parameters that thus need to be defined are the rate at which risk increases with speed, and the relative risk between the different types of design (as illustrated in Figures 1 to 3). A consistent family of curves is derived, assuming that the relative risk between the different designs stays the same.

Many studies (eg Nilsson 1982, Taylor et al 2000) have shown that the risk of accidents occurring on any particular road section increase with approximately the square of the speed increase. This is consistent with the fundamental physical laws, such as braking distances, and also with observed changes in accident data when traffic speeds change (see for example Elvik and Vaa,2004). The increase in risk of accidents with more severe injuries is greater with increase in speed. Based on injury consequences, Nilsson (1982, 2004) suggests that for fatalities, the relationship is closer to the fourth power of the speed. Results from observed studies are more varied but usually show a substantially higher rate of increase for fatal and serious casualties than for all injuries. For the rating curves for EuroRAP, a cubic relationship has been assumed ie the ratio of accident frequency before and after a speed change is the cubed ratio of the speeds before and after – examples are given in the box below.

Examples of effect of use of cubic speed relationship on predicted accident reduction

Speed before km/h	Speed after km/h	Speed ratio -after to before	Cubed ratio	% reduction in accidents
120	110	0.92	0.77	23
120	100	0.83	0.58	42
90	80	0.89	0.70	30
90	70	0.78	0.47	53
60	50	0.83	0.58	42

It should be noted that there is a slight inconsistency in the above discussion in that the injury thresholds defined by NCAP biomechanical data reflect likelihood of fatal outcomes, while the cubic speed relationship chosen for EuroRAP relates to fatal and serious accidents. In practice these choices reflect the data available and recognition that data from both sources are subject to some uncertainty. Any validation of the risk assumptions using observed accident data will rely on the use of data on fatal and serious accidents as fatal accident numbers are too low (section 2.4).

2.3 Choice of road features to assess

This section lists the road elements that are included in the inspection that produces the score showing how well the road protects against the injury consequences of each accident type. In general, the factors chosen are those considered to have a substantial influence on injury severity (eg where research literature suggests the potential for a reduction of at least 10% in severe injury accidents). The estimate of the risk associated with each element is discussed in the next section.

Where more than one element is present in relation to the same accident type, rules have been defined to show which score is used.

2.3.1 Head-on accidents

Three distinct groups of median treatment were defined - (a) central restraint systems, (b) central reserves constructed with a material or physical profiling discouraging vehicle use but without additional restraint systems, and (c) no physical separation between opposing traffic streams (although visual patterns may be used to discourage use of opposing traffic lane).

<u>Restraint systems</u>
It was initially decided that CEN approved restraint systems should be identified separately and given a lower risk score than non-CEN approved systems. But this required that inspectors were able to identify CEN approved systems, which proved difficult during the drive through survey. Most western European countries were expected to comply with CEN requirements. Where they did not, many non-CEN variants might be in use in different countries but it is unlikely that their relative risk could be defined; a single higher risk score could be associated with all these, including systems which were clearly not in full working condition, if they could be identified as such.

<u>Central reserves with physical discouragement to traffic</u>
The key factor affecting risk in this category would be median width. No differentiation is made between differences in the extent to which the median is raised (eg kerbed/non-kerbed) as this was considered too difficult to assess consistently, and unlikely to have a large effect on risk. Four median width bands were chosen to be scored separately – 0-2.99m, 3-6.99m, 7-10m and over 10m. Most but not all of the risk of reaching opposing traffic streams is removed with a width of 10m (eg Ogden, 1996 quotes Zegeer and Council, 1992, finding that with median width of 9m between 70% and 90% of encroaching vehicles do not reach the opposing carriageway).The bands chosen were consistent with the distance bands used for defining roadside edge treatment.

<u>Non-physical separation of opposing traffic flows</u>
Three factors are of interest in relation to this category

- width of separation,
- whether any physical surface treatment is provided to discourage crossing the median,
- whether any marking systems are used to discourage crossing the median.

These factors affect both the likelihood of accidents occurring and the likelihood of injury resulting. In principle the only influence on injury protection will be the extent to which the vehicle entering this space can reduce speed or modify its direction within the space provided, sufficiently to mitigate the injury outcome. For considering injury protection, three groups were defined. Separation of at least 1m wide with some physical treatment such as grooves or rumble strips also present, separation of at least 1m shown only by road marking, and separation less than 1m.

But the likelihood of accidents occurring will also be strongly affected by the extent to which the central treatment discourages vehicles from entering this area, or warns them they have inadvertently entered it. In some countries there is a well established road marking system (eg solid central line marking) whereby overtaking is prohibited by law. For some countries therefore it will be useful also to divide the last category (separation less than 1m) into those sections with an overtaking prohibition and those without. However such a system will have no effect in situations where drivers are inattentive or asleep or make misjudgements of appropriate speed. Such errors are more likely to occur on curves or after longer monotonous straight sections. These factors are not included in the current version of RPS, but are being considered for later versions.[1]

An additional factor that could be considered relevant to injury protection is the level and vehicle composition of the opposing traffic flow that might be impacted if the median is crossed. This is also not included in the current RPS.

2.3.2 Run-off accidents

As for head-on accidents, CEN approved restraint systems would ideally be identified separately, but it is assumed that all other systems may be breached and therefore these are scored according to nearest aggressive object, although the presence of a non-CEN-approved barrier may be recorded separately. Inspectors could be given examples of CEN approved and non-CEN barriers, including steel, concrete and wire rope.

Relatively smooth faced, near vertical cut slopes of at least 2m height at the roadside are assumed to act in a similar way to CEN barriers in constraining errant vehicles and are at present scored similarly, but again these are recorded separately so that there is scope for later adjustment to the scoring system.

Four run-off zone width bands were chosen, as a compromise between the known variation of risk with zone width and the need to give inspectors a realistic task of discriminating between the bands from the moving vehicle. The band widths are the same as those used for median width, 0-2.99m, 3-6.99m, 7-10m and over10m; a substantial proportion of the risk occurs in the first 7m, and this is reflected in the warrants for safety barriers in many countries. The effective zone width could be estimated taking into account the slope of the roadside area, eg reducing the effective distance of objects where there was downward sloping ground, and increasing it where ground sloped upward. Following US and Swedish design practice, roadsides with slopes greater than 1:2 and 1.5m drop, or greater than 1:3 and greater than 5m drop, are recorded separately, and can be scored separately, reflecting the potential likelihood of rollover at these sites.

Hardened "shoulders" of widths less than 3m are known to reduce accidents, mainly by giving drivers more scope to recover from initial deviation out of the running lane. These can be recorded separately but were not scored in the basic version of the RPS. Other features that might be recorded in some environments are the presence of kerbing and of textured edge marking but again these were not included in the basic RPS.

It is not simple to define what is likely to be an aggressive object as there may be a wide variety of objects near the roadside. A list of "hard or aggressive objects" is provided to the inspectors. In general trees and poles are recorded if they have a diameter greater

[1] Likelihood elements have been included in EuroRAP RPS2.0 from 2011.

than 100mm at breast height. Boulders are included as aggressive objects if higher than 200mm (ie where they are likely to cause a vehicle to decelerate rapidly).

Inspectors register single hard objects or stretches with hard objects. The length of road over which a vehicle is at risk of impact with an aggressive object will depend on its distance from the road and the speed of the traffic. At present in the RPS calculation process, the risk score for all single hard objects is applied to a 100m stretch of road, regardless of the distance of the object from the carriageway. Passively safe structures, where these can be identified by the inspectors, are not scored as hard objects.

2.3.3 Junction accidents

As junctions in the basic RPS were scored partly on the basis of potential angle and speed of impact, three groups of junctions were initially established – junctions where only merging manoeuvres at acute angles take place (eg motorway merges), junctions where merging manoeuvres can take place at greater angles (roundabouts), and junctions where right angled impacts can occur (cross roads). Further subdivision of these groups was then made on the basis of the extent to which the junction design leads to lower vehicle speeds at the point of conflict. Thus roundabouts with large deflections can be expected to be safer than those which vehicles can negotiate without slowing substantially. A second potential example is the provision of acceleration and deceleration lanes to enable side road traffic to emerge at a three arm junction at speeds more compatible with main road traffic. However this advantage can be reduced if the lanes are short and result in greater visibility encouraging merging with smaller safety margins. These designs are included in the protocol but care is needed in their scoring. For ease of inspection, only a relatively small number of separate junction types was included; this could usefully be extended in future (see 4.6).

A third factor considered was the presence of controls (eg traffic signals) that should limit the likelihood of collisions although not affecting the injury severity if collisions do occur. A fourth factor was the provision of separate space for turning movements across the main opposing traffic flow; thus intersections with a dedicated turning lane for this movement were recorded separately.

A further factor considered was the traffic flow on the minor arms of the intersection. But this might produce two opposing effects. On the one hand, greater flows are likely to increase the probability of conflicts. On the other hand, serious consequences might be more likely where the presence of a vehicle was unexpected. It was also recognised that actual flows would be unknown and any differentiation could only be defined in terms of clear differences in road design or classification (eg through road numbering).

It was decided in EuroRAP therefore to record only two separate groups of priority controlled minor road access points. The higher flow group were recorded as 3 arm priority controlled T-junctions; the lower flow groups as other accesses. The latter group included private drives, and were defined as any access point where daily traffic might be expected. The decision as to when to record an access point as a priority controlled T-junction was more difficult to decide, and depended to some extent on the network, traffic and accident distribution in a country. More work is needed to check the consistency of these choices. In Sweden, for example priority T-junctions are recorded where the accessing road is a national road (marked with a blue and white road sign). In Germany, all side roads which were not part of the German EuroRAP network (which comprised motorways and State roads) were recorded as “accesses”. For trials in Britain, all roads of lower than Class B joining at a priority junction were scored as “accesses”.

On the basis of these factors, 11 intersection groups were included in the basic scoring regime, although not all were recorded in all countries. The number of lanes on a road section is recorded elsewhere (although not at present scored separately in EuroRAP) so in future scoring might also reflect differences in the number of lanes through an intersection. However, these would be general to the road section as a whole, and would not reflect changes in lane number or lane width localised at the entry or exit to the intersection.

2.3.4 Elements not included separately

Several elements discussed above were not included in the current scoring regime for the basic RPS either because they did not occur in those countries where the RPS was initially trialled or because there was considered to be insufficient evidence on which to base different risk scores. In some cases the items are recorded, but not given a different score. Where the RPS is trialled in a new country where a specific item is considered important in explaining injury protection, it was proposed that this additional item is recorded, as a subgroup of one of the existing groups, and the sensitivity of overall scores, to using a different score for this item, is assessed.

Examples include differentiating median rumble strips and marked strips, differentiating double centre lines and single centre lines, kerbed edges to roadsides or central medians, and raised edge markings.

2.4 Evidence on which to base risk values for each accident type

2.4.1 Head-on accidents

It is generally assumed by many researchers that a median width of 10m on European roads gives a fairly high chance of the errant vehicle being brought to a standstill within the median strip. Relative risks for various median widths are provided by several authors. Most data reflect speeds around 90km/h which are typical of US interstate roads and many European main roads.

Data from Knuiman et al (1993) for example suggest relative risks of 8.5 for 90km/h roads with centre lines only, 7.5 for roads with 1m central marked strip, and 6.5, 3.5 and 2 respectively for median widths of 1-3m, 3-6m and 6-9m, compared with a risk of 1 for medians greater than 9m. These relative risks are more or less in line with other sources (eg Ogden, 1996).

Data for GB roads (Walmsley and Summersgill, 1998) suggests that wide single carriageways (10m compared with 7.3m) have about 20% fewer accidents. Data comparing road widths (eg TRB, 1987) suggests that widening lanes from 2.7m to 3.7m on rural roads might reduce accidents by about 30-50%. This might be considered in width terms as similar to adding a 2m central strip, although the lack of delineation of the extra width as a "separation" area may discourage overtaking less.

In principle, the risk in situations where overtaking is allowed, on non-divided roads, should be considerably larger than in situations where overtaking is restricted. For GB, Walmsley, Summersgill and Binch (1998) indicate that 50% of all head-on collisions on single carriageway rural roads result from overtaking manoeuvres; this suggests that where overtaking is not allowed (and drivers comply with this rule) risk of head-on accidents should be halved. Data from several countries, for example Finland (Safestar, 1997), and US (Highway Safety Information System , www.hsisinfo.org) indicate only around 10% of head-on collisions are linked to overtaking manoeuvres, with the remainder associated with level of awareness, loss of control etc. The difference in proportions is probably due mainly to differences in flow levels, and suggests that separate scoring of this aspect is more relevant on roads with high flows. On the higher flow roads, the frequency of these accidents is likely to be influenced not only by the higher probability of an opposing vehicle being present, but also the smaller number of opportunities to overtake, but the size of these effects is poorly understood.

Elvik and Vaa (2004) conclude that guardrails on medians on multilane roads reduce fatalities by 43%, although different guardrail types affect total number of injury accidents differently, ranging from +15% for concrete barriers to a reduction of about a third for steel and wire rope barriers.

Based on this information, risk curves shown in Figure 1 were developed for head-on accidents, showing the expected relative differences in fatal and serious accidents per vehicle km with various combinations of speed and road design .

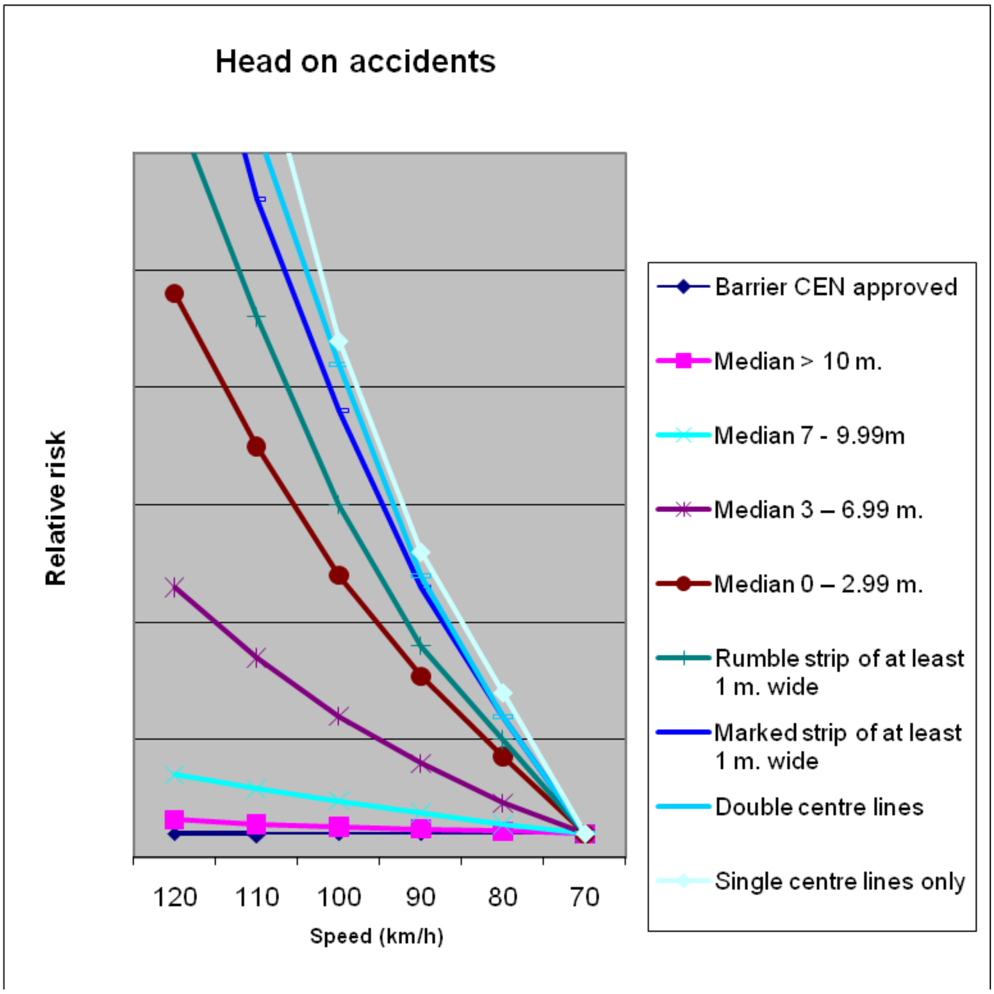

Figure 1 Relative risk curves for different median treatments by traffic speed

2.4.2 Run-off accidents

Many studies (Hutchinson and Kennedy 1966, Sicking and Ross 1986, Cooper 1980, Calcote et al 1985) have estimated distributions of encroachment angles, and most agree that the majority of encroachments occur between 5 and 20 degrees. These relatively shallow angles enable even safety zone widths of 5m or less to have an effect on accident outcome.

Hautala (quoted in SAFESTAR, 1997) suggested that over half of the errant vehicles on rural roads in Finland hit objects less than 3m from the edge of the road, and 88% less than 7m from the road edge. Zegeer et al (1988) investigated variation in accident rate by average roadside recovery distance (i.e. distance from running lanes that is basically flat, unobstructed and smooth within which there is reasonable opportunity for safe recovery of an out-of-control vehicle). A recovery distance of 10 feet (3.3m) was associated with a reduction in related accidents of 25% and a distance of 20 feet (6.6m) with a reduction of 50%. Knuiman et al (1993) found that median accident rates and severity decline rapidly when the median width exceeds about 25 feet (7.6m). Meewes and Kuler (2001) compared run off accident rates for roads with different clearance distances on either side. This study suggested the following reductions in accident numbers might be obtained from varying the clear zone widths – 26% from adding a 3m clear zone, 30-48% from extending a 1.3m clear width to 5m clear width, and 60% from extending a 1m clear width to 8.6m. Studies in the Netherlands in the 1980s (reported in Schoon, 1997) based on accidents on road sections lined with rows of trees at various distances from the edge of the vehicle running lane suggested acceptable obstacle free zones might 3.5m (regional two lane road), 7m (federal two way road, and 10m (motorway). Elvik and Vaa (2004) conclude that increasing the safety zone from 1m to 5m reduces injury accidents by 22%, and increasing from 5m to 9m reduces injury accidents by 44%. They suggest that flattening the embankment slope from 1:3 to 1:4 reduces accidents by 42%, and from 1:4 to 1:6 by 22%. The same authors conclude that guardrails on embankments reduce run-off-road fatalities by 44%, but run-off accidents by only 7%.

These sources are discussed in more detail in Lynam and Kennedy (2005) in a review of the travel of errant vehicles after leaving the carriageway.

The data described above mainly relate to 90km/h roads, and show a fairly consistent variation of risk by distance to obstacles, similar to that shown for median widths. The EuroRAP risk matrix was therefore based on these data for 90km/h roads. Relative risk values at other speeds were calculated using the cube law for change in number of accidents with speed. Values for individual cells within the risk matrix were adjusted slightly where necessary to give a “smooth” family of curves (Figure 2).

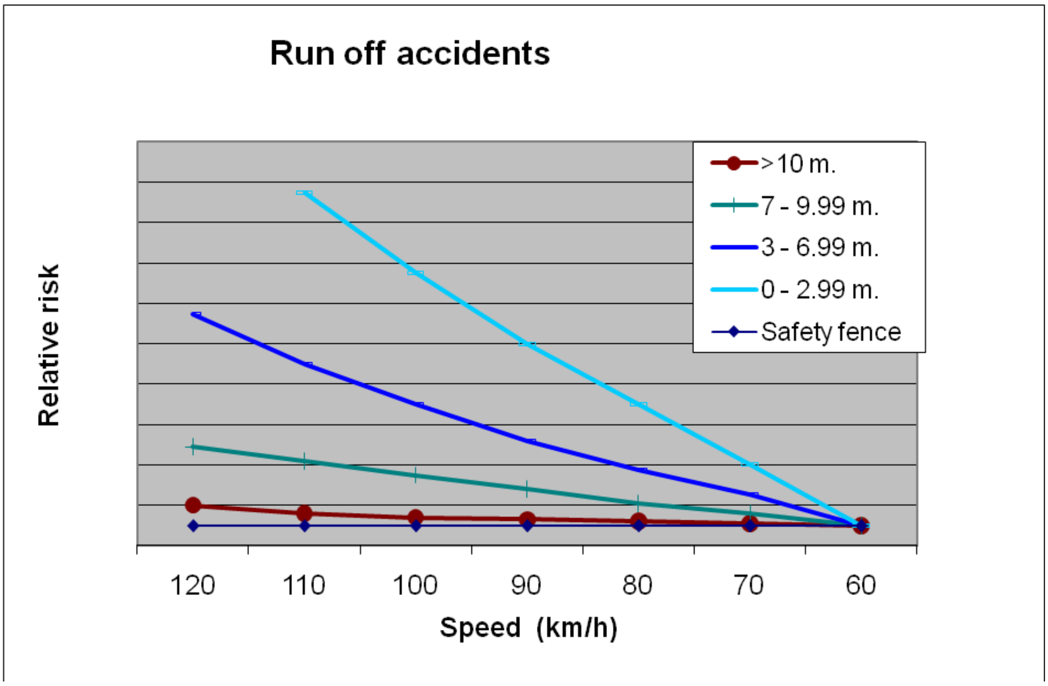

Figure 2 Relative risk curves for different roadside treatments by traffic speed

2.4.3 Junction accidents

Numerous studies have shown the importance of junction density to accident rate. For example in US models (eg Vogt and Bared, 2000) driveway density is shown to be a significant variable. In Britain, Walmsley and Summersgill (1998) suggest adding one extra access to a single carriageway causes up to 1% increase in accidents, but on dual carriageways causes 2-3% increase in accidents. Gluck et al (1999) suggest that compared with a road with 10 access points per mile, roads with 40 access points have double the accident rate, and with 60 access points three times the rate. Hughes et al (1997) suggest that increasing the distance between grade-separated junctions leads to reductions in accident frequency on both on-ramps and off-ramps. Ramps with change in vertical alignment lead to more accidents than level ramps.

However the primary focus of the basic RPS was to assess the extent to which road design mitigates severe injury, not the extent to which it reduces the number of accidents. It is necessary therefore to devise an assessment which relates to the likely severity resulting from different junction types. The focus for the assessment is also the protection provided to car occupants. Thus, roundabouts should score well as they result in very few fatalities to car occupants, although they present greater risk of severe accidents to two-wheeler riders than to car occupants. A scoring regime was thus constructed based on the biomechanical principles associated with the effect of speed and angle of impact on severity of injury to car occupants.

Angle of impact

This regime was developed in two parts. First, for each category of intersection design, an assessment was made of the angle of merging and the extent to which this might reduce collision speed. For example, for motorway merging, impact speeds would be expected to be very little different from the speed of traffic on the motorway. For "merging" manoeuvres where either a very short merging lane or no merging lane at all was provided, collision speeds were assumed to be half or three quarters of the speed limit; this assumes that drivers would only emerge at these junctions if they thought they had space to do so, and collisions would occur in situations where this judgement was incorrect, but would still enable some slowing of approaching traffic. Where, as with roundabouts, merging vehicles were required to adjust their line of approach through say 45 or 60 degrees on entry, collision speeds were assumed to be at quarter or half of the traffic speed on the joining road. Thus for example, a roundabout, on a road with 90km/h speed limit, which requires vehicles to deflect 60 degrees on their approach, should be assessed on the speed/risk curve for a speed of about 45km/h.

Impact speed

Secondly, the starting point of unit risk, on the speed/risk curve is set at different speeds according to the potential angle of impact. These speeds are again chosen to relate to car occupant injury resulting from vehicle impact tests ie for frontal impact unit risk is assumed at 70km/h, for 90 degree side impact at 50km/h, and for 60 degree impact at 60km/h. By combining these two sets of assumptions, a relative risk table is constructed for different junction types on roads with different speed limits. In theory, any junction type could be added to this table, providing an assumption is made of the extent to which the junction affects the speed of approaching vehicles and their angle of impact.

The scoring regime developed in this way can be compared with data on the relative proportion of car occupant fatalities occurring at different types of junction. Data from Germany (Eckstein and Meewes, 2002) show ratios between number of seriously injured persons and the number of slightly injured persons varying between 0.1 for small roundabouts controlled by give way signs, to 0.3 to 0.4 for traffic light junctions, and 0.5 for junctions with give way control by traffic signs only.

On this basis alone, a four star score, which should indicate no fatalities occurring, could result regardless of the number of junctions along the road. For a road with less well designed junctions, an average score for the road might also be obtained as a weighted score of the proportion of junctions of each type, based only on the severity mitigation potential. However as junction density has such a large effect on the total number of fatalities, it was decided that the risk rating should include directly the number of junctions rather than just their relative safety. Thus the junction score for the route is calculated by adding the scores for all the junctions along the route and dividing by route length – in this way both potential for severity and the number of junctions is taken into account.

The risk curves for junctions of different designs are illustrated in Figure 3.

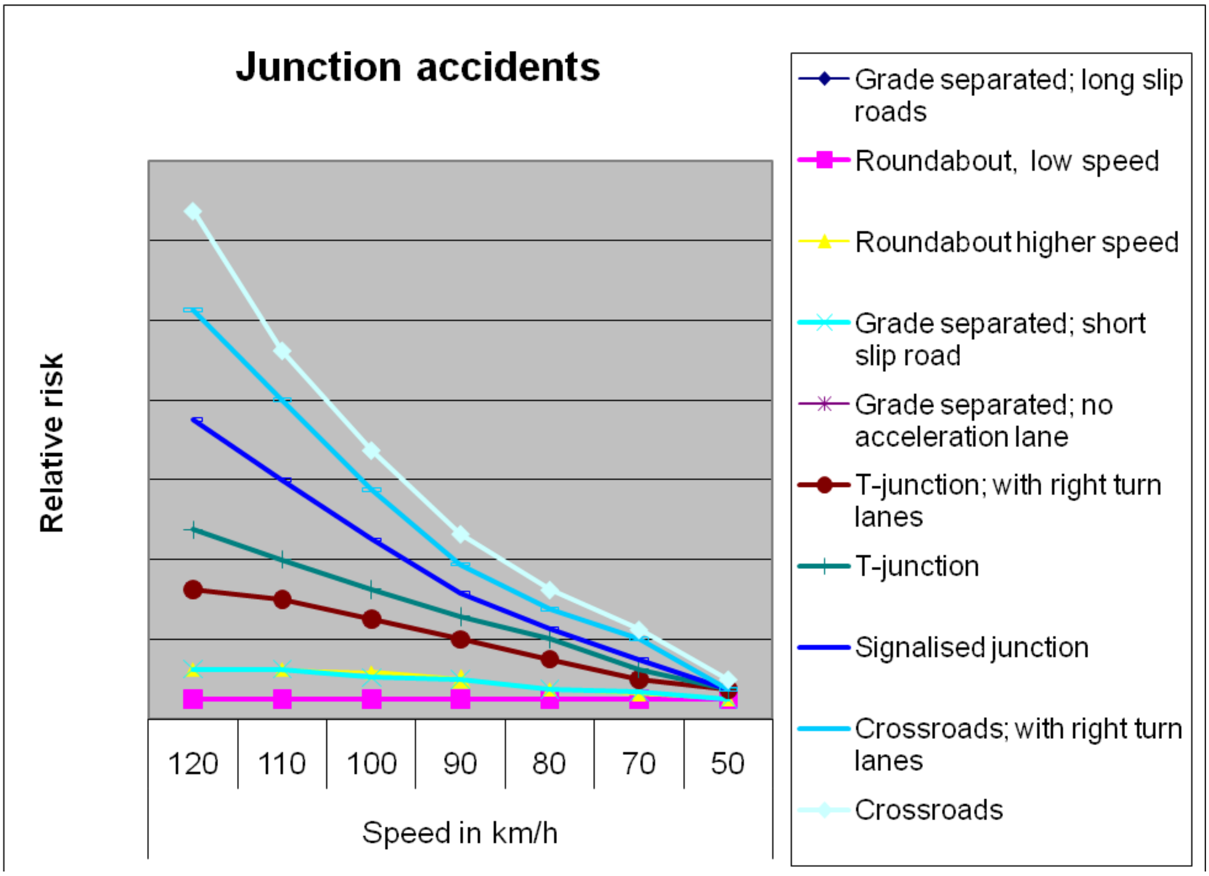

Figure 3 Relative risk scores for junctions of different design by traffic speed

(Risk for grade separated junctions with long slip roads is assumed the same as for low speed roundabouts)

2.5 Banding risk values into star ratings

The risk curves shown in section 2.4 describe a continuous increase in risk with traffic speed, for each road design element, apart from those (eg safety barriers) that are assumed to remain at unit risk through the speed range considered. Risk levels need to be chosen at which ratings will change from the highest band (4 star) to 3, 2 and 1 star. As the curves are based on relative risk, and the ratings for each accident type will be subsequently combined into a single overall rating, it is important that the band thresholds are approximately the same for each accident type. It is also important that ratings for practical combinations of traffic speed and design group, for roads which are considered to have similar overall safety levels, fall into the same bands. Finally it is desirable for roads being assessed to be spread across the rating bands so that differences in risk between them could be clearly seen.

On the basis of these criteria, band thresholds shown in Table 1 were chosen.

Table 1 Risk score band ranges for EuroRAP rating

Rating	Relative risk score for band
4 star	1 -2.9
3 star	3.0 – 5.9
2 star	6.0 – 10.9
1 star	> 10.9

This meant that roads were classed as four star if their risk was less than three times the minimum risk. In theory, a relative risk of 1 means that if all the vehicle and behavioural conditions were fulfilled, no fatalities would occur, but in practice it is likely that a small number of fatalities (and a rather larger number of severe injuries) would still occur. The threshold between 3 and 2 star roads corresponds roughly to a further doubling of risk, and between 2 and 1 star roads roughly to yet a further doubling. The thresholds used for rating run-off and head-on accidents relate directly to these risk scores. The thresholds assumed for intersection accidents are set to the same proportions, but scaled in risk level because they are factored also by the number of intersections.

2.5.1 Intermediate scores

The use of integer ratings gives only a coarse division by risk. Where risk levels are close to the threshold, roads with very little difference in risk may fall into different rating bands. This also occurs with risk mapping bands, and is not a problem at the general level. However for engineers who may be charged with improving the road to modify the risk rating, it is necessary to know more precisely the risk rating, and the action that is required to change to a higher rating. The procedure of combining scores weighted by length of road sections results in an averaged rating that is non-integer. This gives a more accurate picture of risk than simple rating bands. This process can also be used for smaller sections of road within the EuroRAP route if required, although the graphical visualisation of ratings by 100 metre length over the whole section may provide a clearer indication of the variation within the route.

2.6 Assessing results

The validity of the results obtained has been investigated in various ways. An initial approach was to look at roads in Sweden that were assessed as 4 star – which in principle should have no fatal accidents – and see if this was indeed the case. To do this it is necessary to isolate the fatal accidents that only involve cars, specifically those that are rated as 4 star in NCAP, and where no traffic violation such as speeding or non-wearing of seatbelts is involved. When this is done, there are relatively few situations where fatal accidents occur on four star roads (Lynam et al, 2007). This type of analysis has been taken further by Stigson (2008), who has investigated differences in crash pulses from on-board recorders in accidents on roads with different infrastructure ratings.

More direct validation has been attempted by comparison between star ratings and observed accident data. To do this, average fatal and serious accident rates are calculated for roads obtaining different star ratings, with the aim of showing that the higher star roads have lower accident rates. Comparisons across whole networks including a range of road types typically show a strong relationship between star rating and accident rate, but this is heavily driven by the low rates and high ratings to be expected on motorways compared with the higher rates and lower star ratings to be expected on single carriageway roads. Much more convincing comparisons are provided by looking for relationships within road type groups. The range of rating and accident rate within a road group is much less than across all road types but fairly strong relationships can still be seen in the Swedish data (Lynam et al, 2007) and the British data (Castle et al, 2007; Martin et al, 2009). The relationships can further be seen within comparisons for individual accident types. The British comparisons show similar linkages for subsets of the road network as well as for the Highways Agency network as a whole, and the whole primary road network. However it is noted that roads with higher flows among the British data typically have both lower accident rates and high ratings than those with lower flows. It is unclear whether this is a confounding factor in the comparisons, and the extent that this trend reflects the higher flow roads having been improved more because of the higher cost effectiveness of improvements on these roads. Similar analyses of EuroRAP data from Germany and early work in the Netherlands have failed to identify any clear link between ratings and accident rates, although more recent work in the Netherlands is more promising and has pointed to the structure of the data set as being a shortcoming. Some factors have been identified that might explain this difference between the outcomes in the different countries. These factors include differences in the nature of the road sections being grouped (a lack of homogeneity), low numbers of sections being compared in each category, low numbers of severe crashes on each road section, and pre-definition of crash types in a way that is not directly compatible with the risk types being assessed in the Road Protection Score. More comparative analyses are being pursued.

3 Assessing risk within International Road Assessment Programme

3.1 Object of programme

The International Road Assessment Programme aimed to exploit the concepts and models developed during EuroRAP, AusRAP and usRAP but the output required was recommendation of countermeasure programmes rather than simply assessing current road design. The Clients in this case was the potential funders of these countermeasure programmes – typically national or regional governments and international banks.

This required that the risk model outputs could be extended to provide estimates of current casualty numbers and the potential reduction in casualty numbers if different countermeasures were applied, as well as the economic case in cost benefit terms of implementing these measures. This report focuses on the way in which the risk model was developed to enable these requirements to be met.

The programme was aimed at low and middle income countries, and the models chosen reflected the following characteristics of the safety problem in these countries:

- Road deaths occur widely on urban and semi-urban roads as well as rural roads, so the previous RAP focus needed to extend to all these roads
- The majority of road deaths did not necessarily involve car occupants, so models were needed for motorcyclists, pedal cyclists, and pedestrians as well
- Observed accident data were very limited, and thus model estimates of casualties were likely to be the main tool by which to evaluate countermeasures
- The huge accident toll meant that uncertainty in casualty estimates was not critical and models focussed on the main accident factors would be useful, even if some of the safety relationships were only poorly understood

3.2 Structure of risk models[2]

In developing the iRAP risk models, four sources were particularly useful - EuroRAP, AusRAP (AusRAP, 2006) and ARRB work on Risk Manager software, the US Highway Safety model that was in the final stages of development (Harwood et al, 2000), and TRL roadside risk assessment analyses

EuroRAP had focussed on injury protection using a simple 2-way matrix (speed and road design factor) for each of three car occupant accident types. AusRAP had developed a more extensive model including likelihood factors but combined them with protection factors through a series of lookup tables and included an arithmetic component in their model. As with EuroRAP, AusRAP rated for car occupants only, using the same three accident types. The US Highway Safety model, which was in the process of development when iRAP was initiated, used a multiplicative approach, reflecting a series of "collision modification" factors to modify basic risk estimates. Recent UK research had focussed on risk assessment as a product of accident likelihood and injury protection to enable the effect of these separate components to be reflected in the choice of countermeasures.

One initial area of discussion in iRAP was whether to include a road type and area type factor in model. Eventually it was decided to use the same model for all road types, allowing individual road feature factors (eg whether divided carriageway, number of lanes, frequency of junctions, presence of bends) to reflect differences in road type. An "area accident type" factor was included. This had two functions – first it allowed adjustment of the relative risk levels between accident types (if the risk assumed as 1 for one accident type, eg head-on, did not correspond to the risk assumed as 1 for

[2] Descriptions of the iRAP model relate to iRAP model Version 1.0 as it was being used in 2009.

another accident type for the same mode), and second it allowed for adjustment to be made when matching risk scores to observed accidents for roads in different types of area (urban, semi-urban, and rural) if factors not included in the models led to differences between predicted and observed accident numbers (an example is given in 3.2.1). It was found to be much more difficult to define the boundaries between different land uses and their effects on safety in low income countries than in higher income countries. The categorisation of urban and rural areas in any published accident statistics was also less consistent.

A multiplicative model was chosen separating the effects of likelihood and protection factors on risk, as far as possible, with the aim of

- Maintaining the ability in EuroRAP to reflect the protective duties of the road provider (discussed further in 4.2)
- Enabling risk associated with different elements of road design to be introduced as risk amendment factors, in a similar (although much simpler) way to the accident modification factors adopted in the US Highway Safety model
- Being consistent with the general risk assessment methodology being applied in a range of highway and non-highway situations
- Enabling transparency in the risk calculation, and simple modification of the risk factors used, as better information became available on the influence of road design on safety

Thus for each main accident type for each of the four modes a model was developed following the general format:

Risk score = likelihood x protection x area accident type factor

In total, eleven accident type models were used, as listed in Table 2.

Table 2. Model types included for each mode in iRAP

	Accident types		
Car occupant	Run-off	Head-on	Junction
Motorcyclist	Run-off	Head-on	Junction
Pedal cyclist	Along road	Crossing road	Junction
Pedestrian	Along road	Crossing road	

For car occupants, the same model types used in EuroRAP and AusRAP were adopted. In the absence of alternative evidence, the motorcyclist models followed the same accident types. Separate pedestrian models were developed for the risk when walking along the road, and when crossing the road. The former accident type usually only contributes a small minority of deaths in high income countries, but is has much greater influence on the number of pedestrian deaths in low income countries.

There was very little research available on which to base pedal cycle models. For consistency, three pedal cycle models were adopted. "Travel along the road" reflected a mixture of car run-off and pedestrian along road factors, "junction" reflected a similar form to the car and motorcycle models, and "crossing road" reflected a similar form to the pedestrian crossing model.

3.2.1 Factors to be included in each model

A key aim was to keep the number of factors in each model to a minimum; factors were only included if it was generally agreed (through team discussion among representatives of ARRB, iRAP, MRI and TRL) that they had a significant influence on accident or injury risk. Table 3 lists the selected factors, which are described in the following sections.

Table 3. Factors included in each model

Mode	Accident type	Likelihood factors	Protection factors
Car occupant	Run-off	Speed - likelihood Lane width Paved shoulder width Curvature Quality of curve Delineation Road condition Raised edge markings	Speed – protection Roadside severity
	Head-on	Speed - likelihood Number of lanes Lane width Curvature Quality of curve Overtaking demand Road condition	Speed – protection Median type – protection
	Junction	Speed – likelihood Major junction type - likelihood Junction quality Intersecting road flow Minor access point density	Speed – protection Major junction type protection
Motorcyclist	Run-off	As car model, except number of lanes and lane width excluded, but factor for segregated lane or facility added	As car model
	Head-on	As car model	As car model
	Junction	As car model	As car model
Pedestrian	Along road	Speed - likelihood Sidewalk provision - likelihood Side friction	Speed - protection Sidewalk provision – protection
	Crossing	Speed - likelihood Number of lanes Median type - likelihood Pedestrian crossing facilities - likelihood Quality of crossing	Speed - protection Pedestrian crossing facilities - protection
Pedal cyclist	Along road	As car model for run off but factors for Bicycle Lane or Facility and for	As car model for run off

		Side Friction added and raised edge marking omitted	
	Crossing	As pedestrian model	As pedestrian model
	Junction	As car model	As car model

Where segregated facilities (for motorcyclists or pedal cyclists) were assessed, risk values were chosen to reflect the physical characteristics of these facilities (eg roadside character, median treatment).

An example of the estimation of car occupant run-off risk score would then be

Car run-off likelihood risk = a x b x c x d x e x f x g x h

where a to h represent the risk value for each factor included in the model; for most factors the optimum is a value of 1, with higher values (eg 1.25) reflecting increased risk, with the potential for a 20% reduction in risk if that factor could be changed to the lowest risk design.

Car run-off likelihood risk is then multiplied by car run-off protection risk and the area accident factor to give a total "car run-off" risk score. A total risk score for car occupants is estimated by adding the risk scores of the three accident types.

Total car risk score = Car run-off risk score + Car head-on risk score + Car Junction risk score

The use of a simple addition of the three risk scores assumes that the risk for a score of 1 is the same for each accident type. The inclusion of the area accident type in each individual accident type calculation enables this assumption to be adjusted if comparison with observed data indicates that it is not robust. An example is given in the box where an initial assumption of 0.33 for each car accident type might be adjusted to 0.27, 0.30 and 0.43 to better matched the observed distribution of accidents between the three accident types.

Example – adjusting area accident type values to match observed accident distribution

	Accident type			
	Head-on	Run-off	Junction	Sum
RPS score excluding area accident type	1.5	2.6	3.4	
Area accident type factor	0.333	0.333	0.333	1.0
RPS score	0.50	0.87	1.13	2.50
% RPS score by accident type	20	35	45	
Observed % accidents by type	15	30	55	
Ratio % observed to % risk score	0.75	0.87	1.21	
Revised area accident type factor	0.27	0.30	0.43	1.0
RPS risk score with revised factors	0.40	0.80	1.46	2.66

Note: revising area accident type value by simply multiplying by ratio of observed % accidents to % risk score results in a total of area accident type factors which does not equal 1. Adjusting so that the sum is equal to 1 produces a total RPS score different from the original, but the same estimated total number of fatalities is achieved as the fatality factor (see 4.4) changes to compensate for this.

An equivalent star rating (1 to 5) can be defined either for each accident type or for each mode by defining suitable bands of risk score for each star category.

3.2.2 Separation of risk between likelihood and protection

Although the model structure aims to keep accident likelihood separate from injury protection, some design factors clearly affect both, and data are not readily available to separate out each component of risk. Where possible each design feature was assigned to either the likelihood or the protection component of the model, but for "median" and "junction" features, separate factors were defined for each of the two components.

Although EuroRAP nominally reflected only protection, the median risk factors used were based on the total effect of the median (eg by comparing fatal and serious accident rates for different median types). The junction risk factors used in EuroRAP were based only on factors thought to affect injury severity, but this resulted in a relatively poor match with total fatal and serious accidents at junctions on different road types.

Excluding the likelihood factors in the EuroRAP model did not prevent a general match with accident data being achieved as the risks estimated represented the risk for a road with average likelihood factors, and if accident rates were averaged over sufficiently long road lengths they would reflect a "likelihood environment" typical of that road type.

Roadside risk factors

For iRAP, similar risk values for roadside factors were assumed to those used in EuroRAP, but a smaller number of safety zone widths was used. Three run-off zone width bands were chosen, as a compromise between the known variation of both crash and injury risk with zone width and the need to give inspectors a realistic task of discriminating between the bands from the moving vehicle. The band widths are 0-5m, 5-10m, and 10-15m. Several other roadside features such as the presence of a cut or deep drainage ditch are recorded.

Median factors

Initially similar overall risk values were used in iRAP median factors as in EuroRAP, but these were split between likelihood and protection median factors – for example a EuroRAP factor of 8, might become a protection factor of 4 and a likelihood factor of 2. Median widths of up to 20m were also rated in iRAP with only the widest medians having a risk score of 1.

The likelihood of accidents occurring can also be strongly affected by the extent to which the central treatment discourages vehicles from entering this area, or warns them that they have inadvertently entered it. As described in 2.3.1, in some countries there is a well established road marking system (eg solid central line marking) whereby overtaking is prohibited by law. Compliance of drivers in low and middle income countries with such traffic laws was considered uncertain and this feature was not included in iRAP.

An additional factor that could be considered relevant to crash likelihood and also injury protection is the level and vehicle composition of the opposing traffic flow that might be impacted if the median is crossed. To reflect this, the "median likelihood" factor was replaced by an "overtaking demand" factor which varied according to the presence of a median, the number of lanes and the traffic flow.

Elvik and Vaa (2004) suggest that kerbed medians in city streets previously only delineated by road markings reduce accidents by 20%.

Junction likelihood factors

The risk values used for junction protection factors in iRAP were broadly based on those used in EuroRAP, but subsequently differences mainly reflected 3 and 4 leg intersections. The risk values for likelihood factors are broadly based on the values used in AusRAP. iRAP values represent a junction present or absence per 100m, where AusRAP values recorded the potential presence of a junction in every 50m length. iRAP values would therefore be double AusRAP values, if the same rating system was used.

It was calculated that these values imply for example a 22% reduction in risk by adding a turning lane (across opposing traffic) to an unsignalised junction and 14-18% reduction at a signalised junction. US research suggests reductions 28-44% when lanes are installed on one approach at STOP sign controls, and 15-18% reduction for similar installation of lanes at signalised control at rural intersections. US research suggests comparative reductions for urban intersections are 4-14%. AusRAP suggests provision of turning lane reduces KSI by 15%.

US experience (Harwood et al, 2000) suggests that the frequency of all crashes is reduced by about 50% by all way stop junctions compared with junctions giving priority to the major road, but cautions against using all-way stops except on roads with very low flows. The same reference suggests risk with a high density of driveways to be about 50% higher, on average, than with a low density of driveways.

Elvik and Vaa (2004) conclude that (for all injury accidents)

- Accident rate increases with more junction legs, and with higher proportion of traffic entering from side road
- Turning lanes across opposing traffic reduces accidents by about a quarter at T junctions, although evidence is less clear at cross roads
- Roundabouts replacing priority junctions (using Give Way signs) reduce accidents by 31% on 3 leg junctions and 41% on 4 leg.
- Roundabouts replacing traffic signals reduce accidents by 11% on 3 leg and 17% on 4 leg
- Extension of acceleration and deceleration slip roads by 30m reduces accidents by 11% and 7% respectively
- Traffic signals reduce accidents by 15% at T junctions and 30% at cross roads
- Traffic signals which include phases for Right Turn movements reduce right turn accidents by 10% if the phases are combined but by up to 60% if the phases are separated.

Treatment of speed factor

The same speed relationship is used in iRAP as in EuroRAP, with the risk factor increasing as the cube of the speed. This was divided between the two risk components, with the likelihood speed factor increasing linearly with speed and the protection speed factor increasing as the square of speed. European research suggests that likelihood should increase as the square of speed with protection against fatal injury also increasing by the square of speed, but other researchers, particularly in the US (eg TRB, 1998), are not convinced that speed has such a large effect on likelihood, so the compromise described was chosen. For most cases the two components are multiplied together so the separate effects are not so important.

The rating results are still driven very strongly by the traffic speed on a road section, with good ratings only being achieved if road design provides good protection at the operating speed of the road. This use of speed also means that good ratings can be achieved for roads which may look very poorly designed, if the operating speeds on these roads are very low. It is important to recognise that good ratings do not necessarily show a visually well designed road, but one where the likelihood of serious injury is low.

The same broad principles apply to the speed factors used to reflect injury risk to pedestrians and bicyclists. Pedestrian injury risk is based upon data showing the influence of speed on the likelihood of severe injury in car-pedestrian impacts. In the absence of research information (but assumed broad similarity in their vulnerability in collisions with motorised traffic), the same curves have been assumed for cyclist injury risk. Values midway between these curves and curves for car occupants have been assumed for motorcyclist injury severity.

The risk factor values chosen were based upon the research data (eg www.erso.eu) linking risk of pedestrian fatality to impact speed and subsequently amended in the light of new evidence from Montevalli et al (2008). Broadly, fatal injury is highly likely at all speeds above 70km/h but fairly unlikely at speeds of 30km/h.

3.3 Sources of data for new factors in risk models

Data on the risk associated with many of the additional likelihood factors introduced, and particularly on the risk related to non-car road users was sparse. Data available in Europe, Australia, and US were used including that used in developing the AusRAP rating models. For some factors fairly consistent data was available, while for others conflicting data or interpretations were evident. Some factors were included as they were considered potentially important to assessing risk, even though very little data existed on their effects; it was considered important to include them to reflect their potential scope to influence countermeasures and also to highlight the need to collect better data on these factors.

Lane width
This factor is used for run-off and head-on RPS scores for vehicle occupants and for the crossing RPS for pedestrians. Values for vehicle occupants were aligned with those supplied by ARRB for the AusRAP model.

The effect of lane width is not straightforward. Narrower lanes reduce the potential safety envelope around vehicles but may also reduce speeds. Elvik and Vaa (2004) suggest accident rates decline with increasing road width on rural roads, but may increase slightly on urban roads. Increasing lane widths, within a standard design range, may reduce accidents by up to 10%.

Widening lanes by 0.5m at intersections is predicted to reduce motorcycle crashes by 4-6% (Harnen et al, 2003); lane widths of 3.2m or greater are predicted to have 34% fewer motorcycle crashes than narrower lanes.

Paved shoulder width
This factor is only used for vehicle occupant run-off RPS. Values were aligned with AusRAP (based for example on Ogden, 1997)and the US Highway Safety model HSIS, which both suggested risk was reduced by about a third when 2.5m wide hardened shoulders were introduced.

Elvik and Vaa (2004) are more conservative suggesting accident rates 5-10% lower on rural roads which have hard shoulders compared to those without. They also note that utilising extra road space as either wider lanes or a hard shoulder has a similar effect. Some researchers studying the effect of hard shoulders in low income countries have reported increases in risk with hard shoulders. While a hard shoulder should have a positive effect on reducing run-off risk, the considerable variability of width of hard shoulders along some road sections in these countries, coupled with their use as running lanes by slower vehicles and their use by pedestrians, could lead to increased numbers of other accident types. Hard shoulders are also used by slow vehicles in some European countries (eg Sweden, Ireland) which may have influenced the results reported by Elvik and Vaa.

Road curvature

In general, accident studies show that horizontal curves experience higher accident rates than straight road sections, with rates varying from 1.5 to 4 times greater than the tangent sections (Zegeer et al, 1992). These additional accidents are mainly run offs although some will also be head-on accidents where vehicles stray over the centre-line of the bend. Wright and Robertson (quoted in Mak and Sicking, 2003) analysed 300 single-vehicle, fixed-object fatal accidents in Georgia in an attempt to determine encroachment rates at bends and on gradients by comparing the characteristics of the accident sites with controls 1 mile upstream of the accident sites. Bends were significantly over-represented at the fatal accident sites, with the outside of the bend accounting for 70% of the fatal crashes on bends. Downhill gradients of 2% or more were also found to have some effect.

British data (Hughes et al 1997) suggest that on single carriageway roads, an increase in bendiness of 1 degree per km is associated with a one per cent increase in accidents, while on dual carriageways, curves of 25-70 degrees and 70-90 degrees have about 20% and 250% more accidents than road sections with less than 25 degrees of curvature. Taylor et al (2002) suggest that the presence of severe bends (ie those marked with a chevron - which are likely to be greater than 60 degrees) on single carriageway rural roads each add 30% to the accident rate for one km of road. There is additional supporting data from Walmsley and Summersgill (1998) for national roads in England, and from Lamm (1999) for German roads.

Elvik and Vaa (2004) conclude that straightening curves reduces accident frequency if the curve radius is less than 2000m, suggesting that replacing a curve of less than 200m radius by one between 200-400m reduces accidents by 50%; other examples are 200-400m radius increased to 600m giving an accident reduction of 33%, 400-600m to 600-1000m giving a 23% reduction and 600/1000m to 1000/2000m giving an 18% reduction.

Although these data suggest a fairly consistent picture of the average effect of changing road curvature, other local factors can have a major effect on accident frequency at a particular bend. Such factors generally reflect the extent to which drivers fully anticipate the nature of the bend. A driver encountering a relatively sharp isolated bend on an otherwise fairly high speed road is more likely to make a mistake in assessing the risk at the bend than a driver negotiating one of a series of bends which have already caused a slower speed to be adopted. The driver might be given warning of the nature of the bend in various ways; iRAP attempted to take some account of this by including a "quality of curve " factor, but data on which to base a risk value for this is very limited.

Quality of curve

This is an aggregate measure (which inspectors need to judge) which includes advance road signing warning of bend, roadside indicators around the bend indicating its curvature, and the presence of transitions and camber that enable smooth passage through the bend. The lack of this smoothness is difficult to detect from video alone although it might be assessed by rating while driving through a bend. However the factor will remain subjective.

The factor is included as it is recognised that bends which look superficially similar in curvature can have very different safety records. But the reasons for this are poorly understood and in the absence of consistent and strong evidence that the benefits are greater, it may be appropriate to assume that good signing and marking would reduce risk at each bend by only a small amount. Elvik and Vaa (2004) conclude that various advanced warning signs at bends appear to reduce accidents by 10-30%, while directional marking or guardrails with painting may reduce accidents by 20-40%. At the same time they suggest risk in unexpected bends (and notably fewer than 0.5 bends per km) can be around three times higher when compared with risk associated with frequent bends.

Future research might enable this factor to play a more important role in risk assessments.

Delineation
It is assumed that good general signing and marking along a route would reduce risk of head-on and run-off accidents by 20%; a similar effect on intersection accidents is represented by the "quality of intersection" factor associated with each intersection. AusRAP assumed rather higher risk values, but some of this effect is taken in iRAP through quality of bend and junction scores. Elvik and Vaa (2004) conclude that the majority of markings have very little effect on risk.

Shoulder rumble strips and raised edge markings
There is conflicting evidence on the effect of these measures. Elvik and Vaa (2004) suggest shoulder rumble strips can reduce accident frequency by 30% although EuroRAP Swedish representatives suggest raised edge markings are thought to result in a maximum of 15% accident reduction. Some US states (ref FHWA, 2006) report very large reductions in run-off fatalities after introducing rumble strips. Harwood, 1993, (quoted in Ogden, 1996) concluded that shoulder rumble strips installed along extended sections of roadway generally reduced the rate of run-off accidents by 20% or more.

Road condition
The effect of road condition on safety risk is not straightforward. If road condition is very poor, reduced speeds may reduce accidents. Elvik and Vaa (2004) suggest that reconstruction, rehabilitation and resurfacing of roads can reduce the number of injury accidents by about 20% in rural areas, but by less than 10% in urban areas. Improving surface friction can reduce accidents by up to 40% on wet roads, but can also affect driving speeds.

iRAP inspectors were asked to rate roads in relation to the presence of potholes or obstacles that might cause road users to swerve or lose control of their vehicles.

Number of lanes
Elvik and Vaa (2004) point out that increasing the number of lanes does not appear generally to improve safety; although it can reduce the need for overtaking using opposing lanes, more lanes may lead to increased speeds and will require wider crossings. The number of lanes was originally included in the vehicle occupant head-on RPS, but factor values were set to 1 throughout, as the number of lanes is now one of the factors that determines "overtaking demand".

Overtaking demand
This is a composite set of categories derived from inspection items covering median type, traffic flow, and number of lanes.

Relative overtaking demand scores have been chosen to reflect, when combined with the median protection scores, the general pattern of differences observed in EuroRAP for head-on risk per vehicle km with different central road treatments. Four categories (none, low, medium, and high) are used.

The number of vehicles wishing to attempt overtaking manoeuvres will increase as flow increases but the opportunities for safe overtaking will decrease. If more than one lane is provided in each direction, for undivided roads overtaking demand is assumed as low, and for divided roads overtaking demand is assumed as None. For two lane undivided road, scores are assumed as Medium for central hatching, Low for rumble strips and None for all median widths (with or without barrier). For roads with only central line markings, High scores are assumed for any flows above 4000 AADT (but following AusRAP in varying factor values with flow, a Medium score could be assumed for flows below 4000 AADT).

Junction quality
This is an aggregate measure (which inspectors need to judge) which includes advance road signing warning of a junction, and clear markings and furniture at the junction itself; ideally the site lines to the junction (eg whether closely following a bend) could also be taken into account. In the absence of robust research evidence an initial assumption might be that "good" signing and marking might reduce risk at each junction by 20% compared with "poor". Elvik and Vaa (2004) suggest improvements to road markings and channelization at junctions can reduce accidents by 15%.

Intersecting road flows
Accident frequency at junctions is a function of both major road and minor road flows. The RPS risk score reflects the risk per vehicle on the rated road, but a factor is needed to increase this risk with increasing side road flow. As it is unlikely that data will generally be available on side road flow, a simple high/medium/low flow categorisation was used, based on side road appearance.

Minor access point density
This factor is only used for urban and semi-urban road types where counting individual junctions impractical – in rural areas, individual accesses are counted and their risks aggregated. Ogden (1996) quotes Cirillo (1992) as stating that studies from 1960s and 1970s show accident rate increasing rapidly with driveway density. Elvik and Vaa (2004) report that reducing the number of private access roads from more than 30 to 16-30/km reduces accidents by 29%, reducing from 16-30/km to 6-15/km by 31%; and reducing from 6-15/km to under 6/km by 25%. Roads with private accesses with a total flow of up to 60 vehicles per day emerging from the private accesses per 0.5km of roads have an accident rate about one third of those with emerging flows over 500 vehicles.

<u>Motorcycle model factors</u>

In general the same factors are assumed as for car occupants, except for the features highlighted below. In addition an injury protection/speed relationship is assumed for motorcyclists roughly midway between that for car occupants and pedestrians. Because of the range of paths that motorcycles can take within traffic streams, the three models defined for motorcyclists (run-off, head-on, and junction) are likely to capture less of the total motorcyclist fatalities than these models do for car occupants.

Separate facilities for motorcyclists
There is some evidence (Radin Umar et al, 1995) that providing segregated facilities for motorcyclists can halve the number of motorcyclist fatalities, but this depends heavily on the design of the facilities and the way they interact with other traffic at junctions. In principle, where segregated tracks are available, the run-off and head-on risk values should reflect the design of that track.

Motorcycle friendly barriers
The risk of fatalities to motorcyclists impacting standard safety barriers is higher, perhaps up to twice as high, as that for car occupants. Elvik and Vaa (2004) quote that a change to more pliant guardrails can reduce run-off fatalities by about 40%, but it is not clear whether this relates to motorcyclists.

Junction likelihood
Until further information is available, most of the factors and their risk values are assumed to be generally the same for motorcyclists as for car occupants. One specific difference is the use of a likelihood factor twice as high as that for cars, for motorcycles at roundabouts.

Davies et al (1997) shows data from Kennedy (1997) for urban roundabouts suggesting that accident involvement rates might be twice as high for motorcyclists and three times as high for pedal cyclists at 4-arm roundabouts compared with traffic signals or crossroads. Differences may be less for three arm roundabouts, but in all cases the data are confused as the factors appear to vary with relative car and pedal cycle flows, with rates per cycle flow being higher where other vehicle flows are higher and cycle flows are lower.

Analyses in Davies et al (1997), based on Maycock and Hall (1984) analysis of pedal cyclist accidents at roundabouts, suggest that if cycle flow is increased fourfold, then cyclist accident rate is reduced by about 40%. Part of this effect is built into the flow factor risk values where a factor of 1.75 is used for high flows compared with a factor of 1 for medium flows - but the extent to which this reflects the true differences will depend in part on the interpretation of High, Medium, and Low flows in each country.

<u>Pedestrian model factors</u>

Sidewalk protection type
This item only applies to pedestrian protection RPS along the road and reflects the reduced risk if a pedestrian barrier is provided. The risk value will depend on the assumed resistance of the barrier to breach by errant vehicles.

Sidewalk provision
This is a composite set of categories, derived from inspection items covering sidewalk provision, paved shoulder width and unpaved shoulder width. This item only applies to pedestrian RPS along the road.

Providing space to walk at least 3m separated from the vehicle carriageway is assumed to halve the risk of walking on a narrow (>1m) roadside edge. Walking on the road is assumed to be twice the risk when walking on a narrow roadside strip (Hills et al, 2002, using Papua, New Guinea data, suggests pedestrian accidents decreased by 50% with 1m unsealed footway). Risks for intermediate provision have to be interpolated. In a highly developed country context, Elvik and Vaa (2004) concluded that providing tracks for walking beside the road reduced pedestrian accidents by 35%; physically separating this track by raising and adding kerbstones provides a further 5% reduction.

Side friction
At some sites in low- and middle-income countries, roadside activity spills over onto the roadway so that the edge of the road is poorly defined and pedestrians are likely to walk in the roadway. This can have varied effects on traffic flows and road user behaviour. A risk factor for this situation is only applied to pedestrian RPS along the road in iRAP. High side friction is assumed as an initial conservative estimate to increase risk by 20%. Although there are some indications from experience in low income countries that the

effects might be substantially higher, it is not clear how much of this effect is covered by other risk factors.

Crossing type protection factor
This item only applies to pedestrian RPS crossing the road. The value for a grade separated crossing should be zero if all pedestrians at a site used it. In practice a value should probably be chosen to reflect the extent to which pedestrians still attempt to cross at grade. It should primarily be used to reflect the potential effectiveness of introducing this measure. In the context of highly developed countries, Elvik and Vaa (2004) quote grade separated crossing facilities as reducing pedestrian crossing accidents by 82%.

Crossing type likelihood factor
This item only applies to pedestrian RPS crossing the road. The provision of marked crossings generally only improves safety where there is sufficient pedestrian and traffic flow to result in significant numbers of pedestrians making risky crossings when the marked crossing is absent. For example, Ward, 1992, (quoted in Ogden, 1996) suggests on the basis of British data that installation of refuges near pedestrian generators can reduce pedestrian accidents by as much as 60% but where they are introduced at uncontrolled intersections, even for safety reasons, accidents are only reduced by 10%; if no safety reasons exist, accidents can increase. But risk at marked crossings is also very dependent on drivers respecting the need to stop for pedestrians. Both pedestrian and driver behaviour in low income countries is likely to be different from that in high income countries. However, in South Africa, a properly designed refuge island (at least 1.5m wide) is also assumed to reduce pedestrian risk by 50% (Asian Development Bank, 1999, quoting CSIR,1992).

Elvik and Vaa (2004) also conclude that results from research studies of pedestrian risk are variable; ordinary marked crossings can increase both pedestrian and vehicle accidents, although injuries in the vehicle accidents are not likely to be severe. They suggest that refuges on crossings reduce pedestrian accidents by 18%; pedestrian guard rails at crossings reduce pedestrian accidents by 24% (33% with visi-rail), while the effects of pavement widening are unclear. Providing traffic signals at crossings reduces total accidents by 5-10% and pedestrian accidents by 12%.

Pedestrian crossing quality
This is an aggregate measure (which inspectors need to judge) which includes advance road signing warning of the crossing, roadside indicators at the crossing itself, and intensity of road marking (including texture differences) on the crossing. In the absence of robust research evidence an initial assumption might be that “good” signing and marking might reduce risk at each crossing by 20% compared with “poor”. Traffic signal crossings are treated as a separate crossing type.

Number of lanes and width of lanes
Pedestrian crossing risk is assumed to increase with width and number of lanes. In the absence of clear evidence, the effect of lane width on pedestrian crossing risk is assumed to increase linearly with the increase in width but is not currently included in the iRAP model. For the purpose of the iRAP model the primary feature of the number of lanes has been used to address this risk.

Median type (pedestrians)
This item relates to pedestrian and bicyclist crossing RPS. Values are based on the presence of a median refuge halving crossing risk; other values are interpolated. The main purpose of this item is to reduce the risk for crossing pedestrians where the road is divided but no marked crossing is present. Pedestrian refuges should be at least 1m

wide and cyclist refuges/medians should be at least the length of a cycle (approximately 2m) before qualifying as a safe refuge. Continuous median strips of at least 1m width were given a similar but slightly lower risk than isolated refuges. Median strips of less than 1m width were given a higher risk. Typical rating results using the values for different layouts are illustrated in section 4.3.

Bicycle model factors

Until further information is available, the factors and risk values are assumed to be the same as for the car occupant or pedestrian models, except that, as with motorcycles, a factor was also included representing the presence of bicycle facilities, either on road or segregated. The injury protection/speed relationship for bicyclists was assumed to be the same as that for pedestrians.

Facilities for bicycles
Initially these have been assumed to have a similar effect on bicycle accidents as the motorcycle facilities have on motorcycle accidents. Elvik and Vaa (2004) suggested there was little evidence that cycle tracks reduced bicycle accidents, but this appears mainly due to the increased cycle flows they encourage so the risk per cyclist should reduce. They suggest physically separating bicyclists onto a separate pavement reduces bicycle accidents by 30%, but cycle lanes on the road only reduce cycle accidents by a very small percentage. Cycle lanes through signalised junctions reduced cycle accidents by 12% but increased vehicle accidents by 39% leading to an overall increase in total accidents of 14%.

Crossing facilities
Until further information is available, the factors and risk values were assumed to be the same as for pedestrians. Cyclists are assumed to gain similar advantages to pedestrians from using the pedestrian crossing facilities. But for full benefits for cyclists, the median or refuge width should be at least the length of a bicycle (approximately 2m).

Junctions
As with motorcycles at intersections, the factors and risk values for bicycles are assumed to be generally the same as for car occupants. The main difference is at roundabouts, where a likelihood factor for bicycles three times as high as that for cars is assumed

Side friction
In the absence of any other data, the same factors were used for bicyclists as for pedestrians

3.4 Use of Flow Factors

The EuroRAP risk maps based on observed accident data represent the risk to car occupants in relation to total vehicle flow. As such they represent one component of total risk on the road, albeit the major one on rural roads in higher income countries; where risks associated with other road users or other accident types are shown (eg Lynam and Lawson, 2005; Lynam et al, 2007) they are given similarly as risk for that road user or accident type as a function of total traffic flow. Thus by adding these components the total risk per traffic flow on the road section can be shown. The EuroRAP RPS reflects the risk to individual car occupants; it also aims to catch primarily the risk associated with road design factors. Hence it is similar but not the same as the risk shown in the risk maps.

When utilising the RPS as a stepping stone to the iRAP casualty estimates, some adjustments are needed to these definitions in order to be able to translate RPS into casualty numbers. In the low income countries, the traffic mix can vary considerably from that in high income countries, and modes other than car can dominate the accident pattern. In this case it is necessary to use different flow factors for each mode when estimating casualty numbers for that mode.

Casualties = RPS x mode flow x country factor

To estimate casualties associated with motorised vehicle flows (ie car occupants and motorcyclists), the proportion of motorcyclists on a rated section was estimated, and the mode flow for motorcyclists calculated as the proportion of the total flow. Car flows were approximated as the residual proportion of the flow. Ideally the flow of other 4-wheel vehicles would also be estimated and subtracted from the residual proportion, before the remainder was regarded as car flow, with separate models reflecting casualties to other vehicle occupants.

For both car occupant risk and motorcycle risk, fatality estimates might be assumed to increase linearly with the flow of each mode, although there are indications in research studies (eg Lynam et al, 2005) that, for example, motorcycle fatality numbers vary according to the proportion of motorcycles in the flow as well as the absolute motorcycle flow.

Flows of pedestrians and bicyclists were classed as either low, medium or high based on observations during the inspections and any other local knowledge, and separate risk factors assigned to each group.

For pedestrians and bicyclists, the interaction between the vulnerable road user flow and the motorised vehicle flow is better documented, with studies (eg Brude and Larsson quoted in Elvik and Vaa, 2004) suggesting pedestrian and bicyclist casualty numbers vary as the power of about 0.6 to 0.7 of the mode flow (and the square root of the motorised vehicle flow). This implies risk per pedestrian or cyclist declines strongly as their flow within the traffic stream increases. To allow for this, the flow risk factors associated with higher or lower pedestrian flows were estimated using a non-linear relationship around an average flow.

Although these flow factors represented a fairly crude approximation of the effects of interacting flows on casualty risk to non-4 wheeled vehicle users, it is relevant to note that they were applied to crude estimates of the flows of these users as no prior recorded data were available.

A fuller description of the process used for estimating casualties within iRAP, including definition of the "country fatality factor" is given in 4.4 below.

3.5 Assessment of iRAP risk models

The aim of the iRAP programme is to show the general shape and size of potential improvement programmes for the low and middle income countries. Ratings can be used to identify individual road sections that appear to warrant improvements but these should be tested by ground inspections. The improvement programmes proposed for the four initial trial countries were generally recognised as plausible by local safety engineers (iRAP, 2008).

To date there has been less work aimed at validating the risk models directly. One main reason for this is the lack of good accident data from the countries in which iRAP has been applied, which means that accident rate/rating comparisons of the type made for EuroRAP have not been possible. A paper by Harwood et al. (2010) on the application of iRAP to a sample of US roads has found evidence of a relationship between star ratings and crash rates, and this and other work is reviewed by iRAP at http://www.irap.org/library/doc_download/97-crash-rate-star-rating-comparison-paper.html. The structure of the data set in the US may be conducive to demonstrating the relationship – it includes larger and longer samples of road sections than some other data sets, and road sections that are relatively homogenous compared with Europe in design and layout. Martin et al (2009) show some results for Britain of applying a partially extended EuroRAP model in a similar format to the iRAP car occupant risk model. The relationship between accident rate and star rating is less strong than that for the basic (protection elements only) EuroRAP ratings, but this may result from this model not fully representing all iRAP parameters.

An alternative approach to assessing the models is to look at their internal consistency and at the typical accident type patterns that their application produces. Extensive review of the initial results from the iRAP analyses, while indicating some improvements that could be made to both the models and to the risk factor values, failed to reveal any major inconsistencies in the results obtained.

The iRAP ratings are spread over 5 bands, so that the best roads are now rated as 5 star. This is consistent with the bands used in AusRAP, and with the rating range used more generally, eg for hotels etc. EuroRAP initially followed the EuroNCAP practice of using 4 stars, but that has subsequently been extended to 5 stars to enable additional features to be captured.

4 Understanding model outputs

This section shows how the results from applying the risk models can provide information to both road users and road managers, and relates these results to current views on road standards and future network strategies.

4.1 What is being assessed?

The risk score on which the RPS rating is based represents the relative risk to individual road users within in each mode group, in terms of fatal and serious accidents per vehicle km. This shows the risk that each road user faces.

Ideally all road sections that are high risk for any road user would be improved so that no road users face high risk; this is a basic philosophy of Zero Vision policies. But in practice, priority for improvement should be given to the roads where the highest number of severe injuries can be saved. This means information is also needed on casualty numbers, not just risk. With the EuroRAP RPS results, an estimate of potential casualty saving as a result of network improvement can be made by relating star ratings to average accident rates (Castle et al, 2007). With iRAP, a direct estimate of casualty numbers is made from the risk score (section 4.4).

The availability of both individual risk and casualty numbers based on the same data enables the safety issue to be represented from the point of view of both road users and road managers, and provides a basis for debating the standards the road network should meet; this is discussed further in 4.2.

A second important feature of the RPS rating is that it aims to capture the risk on a road section that relates directly to the design of the infrastructure on that road section. An injury accident results from a chain of events, starting with an initial event probably resulting from several factors, which leads to a dangerous situation. If action is not taken to avoid it, a crash will occur. The severity of injury of that crash will depend on the kinetic energy involved in the impact. The outcome can be modified by intervening at any point in this chain to reduce the kinetic energy to a tolerable level. But the most direct way in which the infrastructure can mitigate serious injury is the provision of “forgiving” structures that do not give rise to high energy if impacts do occur, and road designs which separate road users from high energy conflicts.

Thus the initial EuroRAP assessments focussed on the road features which affected “injury protection”. Extending this to include accident likelihood, as in iRAP, involves consideration of two further sets of factors that might affect the incidence of high energy impacts. One group covers the factors defining road user behaviour, such as speeding, seat-belt use, alcohol use and inappropriate or injudicious actions. The other is the measures that might be taken by road managers to try to mitigate inappropriate behaviour. The RPS accident likelihood component aims to capture the second of these. The assessments are made on the assumption that vehicle drivers are behaving within the law (eg keeping to speed limits and wearing suitable protective restraints) but that their injudicious behaviour can be reduced by better information provided by road managers.

One result of this is that casualty estimates based on RPS ratings will not necessarily be good predictors of observed casualty numbers, where the latter are strongly affected by driving violations or by use of vehicles with poor crashworthiness.

As in general different measures are used to influence injury protection and accident likelihood, it is useful to be able to consider these components separately within the risk models. The ability to see the extent to which risk arises from these different sources also provides useful information for discussing individual and societal responsibilities in working towards a safe network.

4.2 Information for Consumers and Road Managers

As indicated in 4.1, there is some potential conflict between an individual's desire to be able to use any road without risk of severe injury and the road network manager's task of working within a defined budget and meeting mobility and environmental objectives as well as safety objectives. These leads to two basic questions - What should individual road users expect? – and - What level of safety should society provide and how much should be invested in improving network safety?

Road managers have a responsibility to ensure the road environment minimises the likelihood of severe injury as long as the road users operate within the traffic laws. They also have a responsibility to provide road users with good information about road factors which might increase the likelihood of accidents, but the outcome of the presence of these factors will ultimately depend on the behaviour of the road users.

Although road managers might wish to eliminate all fatal and serious accidents, in practice their actions are likely to be constrained by the costs of achieving this and by the need to weigh safety benefits against other transport and environmental objectives. Improvements that are justified for roads carrying high flows will not provide the same cost-benefit returns as the same improvements on lower flow roads. In the latter case therefore, safety measures might need to focus on helping drivers to understand the factors giving rise to risk and the way in which they can modify their behaviour to reduce this risk, rather than modifying the physical environment. Risk information therefore needs to be provided from several different viewpoints in order to demonstrate the way in which benefits to individuals and to society as a whole vary, and to enable informed debate about the balance to be reached between these two types of benefit. The risk information provided by EuroRAP and iRAP models can be presented in different ways to help this debate.

EuroRAP produced four different maps representing the observed accident data – accident density, individual accident risk, risk in relation to common road groups, and potential for accident reduction (Lynam, 2005). Although accident density shows the roads with the highest number of severe injuries, these are not necessarily the most effective roads to treat, as within any group of roads those with higher flows will usually have higher accident numbers even if built to high standards. Thus the potential for accident reduction map provides the most relevant information for road managers. Unless an unlimited budget is available for road improvement, and those improvements can be made without, for example, unacceptable environmental consequences, not all high risk roads are likely to be improved. This will be particularly the case for roads with low flows. On those roads where improvement is not funded, road users need to recognise that risk will remain high and understand the sources of this risk and how their behaviour can reduce the chance of serious accidents.

However the more money available for upgrading the network, the more high risk roads can be improved. Castle et al, 2007, give examples of the implications of using current standard cost effectiveness calculations to assess which improvements are worthwhile. The value of saving lives on which these calculations are based has been developed from "willingness to pay" survey techniques. The type of analysis enabled by the EuroRAP network-wide assessment demonstrates the implications of these values. The results can be used to highlight the inconsistency between the measures that appear cost effective using these values, and the measures more commonly demanded by road users.

In a similar way to the observed accident risk maps, RPS risk scores obtained through the models described in this report can be used to show individual risk, estimated accident numbers per km, and potential benefits from various road improvements. The potential for accident reduction shown in the current EuroRAP risk maps was based on comparing observed accident frequencies with the average accident rates for road group.

With RPS, potential accident reductions could be based on achieving target ratings which related more directly to a particular road standard.

4.3 Risk curves and star ratings

How are star ratings defined from the model risk scores, and what road designs are typical of different star ratings? How is this affected by the operating speed of the road? What design is appropriate to be regarded as a 5 star road? What improvement is generally likely to be achievable for particular types of road?

The curves below illustrate the answers to some of these questions. They are based on the risk values used in the initial iRAP models, which may have subsequently been improved, but the aim is to show the basic underlying structure of risk and rating variations. To do this "basic good quality road designs" are illustrated; the characteristics assumed for these are shown in Table 4.

Table 4. Basic "good quality" road type specifications

	Motorway (divided road)	Single carriageway 2 lane
No of lanes	3	1
Lane width	Wide	Wide
Hard shoulder	>2.4m	>1m <2.4m
Curvature	Straight	Straight
Roadside	>10m	5-10m
Median type	(CEN) barrier	Rumble area
Overtaking demand	None	Low
Junction type	Merge	Roundabout
Junction frequency	1 per 3km	1 per km

Car occupant risk curves

Figure 4 illustrates risk curves from the iRAP car occupant models, showing how ratings vary as operating speed on the road changes. The rating bands are shown as 5 star (green), 4 star (yellow), 3 star (orange), 2 star (red) and 1 star (black). Good quality motorways are rated as 5 star up to speeds of about 120km/h. Undivided two lane roads rate 5 star up to about 65km/h, and 4 star up to 80km/h; above 100km/h they drop to 2 star. The risk score for a motorway at 120km/h is thus similar to that for a 2 lane undivided road at about 60km/h.

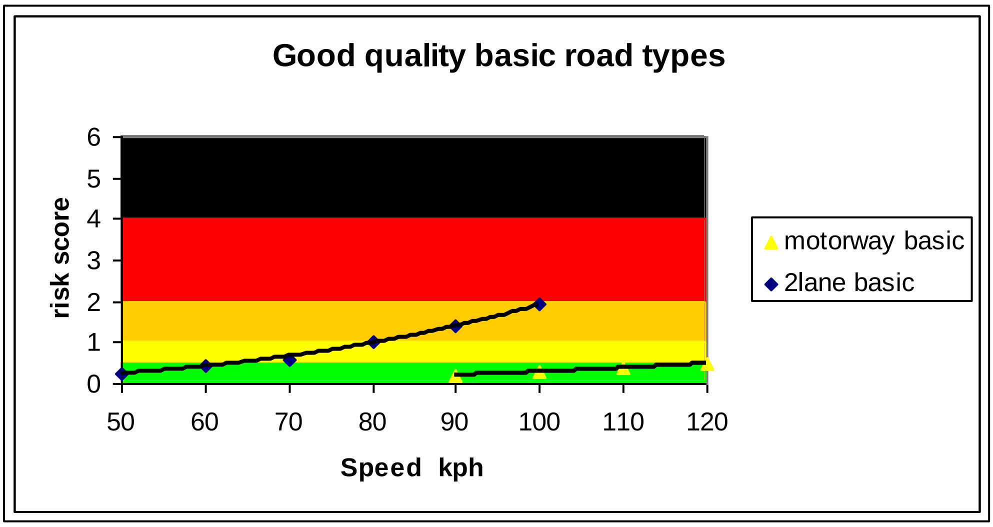

Figure 4 iRAP risk curves for car occupants for good quality basic road types.

Some further discussion of EuroRAP and iRAP car occupant risk curves is given in Martin et al (2009).

Motorcyclist risk curves

Using the same star bandings, the equivalent ratings for motorcycles for the same basic good quality roads are shown in Figure 5. The shape of the curves differs slightly as the fatality by speed relationship reaches a maximum at a lower speed than for car occupants. In very general terms for undivided roads, the rating for motorcyclists would be around 1 star lower than for car occupants, at the same speed. Where good basic single carriageway roads are rated 4 star for car occupants up to 80km/h, they would be rated less than 3 star for motorcyclists at speeds above 70km/h. The initial model used wider rating bands for motorcyclists. This allows greater discrimination between motorcycle ratings for different roads at the lower ratings, but leads to situations where ratings for motorcyclists appear as good as or better than for car occupants. This is only tenable if it is assumed that the ratings for different modes cannot be compared.

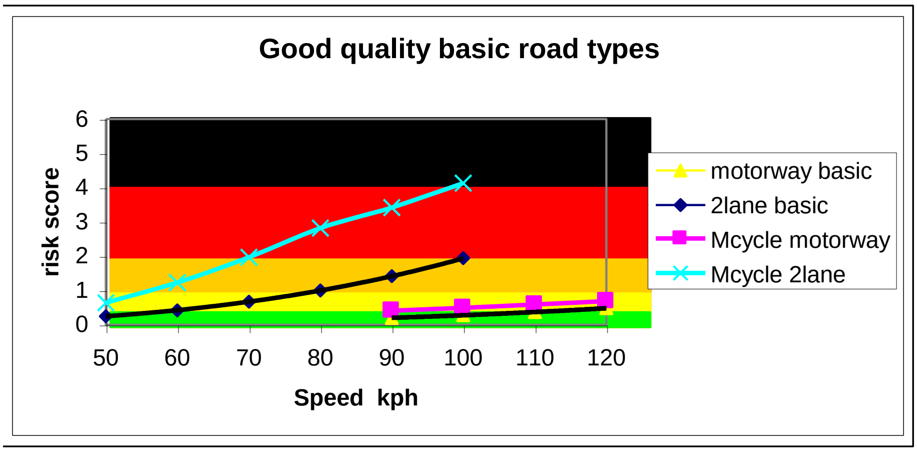

Figure 5. iRAP risk curves for car occupants for good quality basic road types.

Pedestrian risk curves

Pedestrian ratings are more difficult to illustrate as they vary with numbers of crossings per km as well as crossing type. Tables 5 and 6 indicate the rating distributions the model produces. All crossings are rated as 5 star when speeds are as low as 30km/h, but ratings decrease as speeds increase. The presence of a single crossing may give a high rating for that 100m road section but will not have a substantial effect on the rating of say a 1km section of road unless there are frequent crossings.

Table 5 gives examples of the ratings for each crossing type for the 100m section in which they occur. On undivided 2 lane roads, grade separated crossings and traffic signals with refuges are rated 5 star at 60km/h, but traffic signals plus refuge rating drops to 3 star at 100km/h. Most other crossing types (traffic signals without refuges, striped (zebra) crossings, and refuges alone) are rated 3 star for most speeds although their risk scores steadily increase (allowing accident savings if crossings are improved). Ratings for undivided roads with 2 lanes to cross in each direction are substantially worse. Ratings for divided roads (2 lanes in each direction) are half those for undivided roads, resulting in ratings for a road with a continuous median being similar but slightly better than an undivided road with refuges every 100m.

Table 5 Risk scores and ratings for different crossing types on different roads

	Rating per crossing						
Speed km/h	Grade separated	Signals + refuge	Traffic signals	Zebra + refuge	Zebra	Refuge	None
	Undivided 1 lane each way						
100	4*	3*	3*	3*	3*	3*	2*
80	4*	4*	3*	3*	3*	3*	2*
60	5*	5*	4*	4*	3*	3*	3*
	Undivided 2 lane each way						
100		3*	3*			2*	1*
80		3*	3*			2*	1*
60		4*	4*			3*	2*
	Divided (physical median 1-5m) 2 lane each way						
100		4*					2*
80		4*					2*
60		5*					3*

Table 6 shows the variation in ratings for different types of provision alongside the roadway. At 50km/h, sidewalks adjacent to the road are rated as 5 star, but these become 3 star for 80km/h and 2 star for 100km/h. Sidewalks separated by a physical barrier are rated as at least 4 star, and 5 star for speeds of 60km/h or below. If there is no provision for walking alongside the road at all (ie pedestrians have to walk in the road), this is rated as 1 star for speeds above 60km/h, but 3 star if speeds are only 50km/h. If pedestrians can walk on a verge or shoulder, this is rated as 2 star at 100km/h or above, and 4 star at 50km/h.

Table 6 Risk scores and ratings for different roadside provision for pedestrians

	Pedestrian provision alongside road				
Speed km/h	Planned Sidewalk			No walking space	Shoulder 1-2.4m wide
	Physical barrier	Separate by >3m	Adjacent		
120	4*	2*	2*	1*	2*
100	4*	3*	2*	1*	2*
80	4*	3*	3*	1*	3*
60	5*	4*	4*	2*	3*
50	5*	5*	5*	3*	4*

4.4 Countermeasures and casualty estimates

Although EuroRAP was initiated as a consumer information tool, the outputs can be used to provide an overall assessment of network safety and to highlight those routes where safety improvements would be most cost-effective. Examples are given in Castle et al, 2007, at three levels – assessing overall network standard, identifying overall routes for treatment, and identifying sections within routes. The data are not appropriate for identifying localised high risk sites, although this can be done with fuller iRAP survey data, if this is recorded at 100m intervals. But the RPS data provide two advantages over many other data sources – first, they provide a way of assessing large networks on a consistent basis, as opposed to focussing only on higher risk site data, and second they aim to reflect the specific influence of infrastructure design on safety.

Lynam and Lawson (2005) use the EuroRAP risk mapping data based on observed accident data to show how each of the accident types on which the RPS is based contributes to total risk on different road types. This analysis is used to assess the potential for risk reductions on major inter-urban roads in Britain if measures were introduced to reduce the numbers of accidents of each type. Castle et al, 2007, show how the risk associated with each accident type varies with star rating and use this to assess the benefits that could be obtained by improving the star rating of different road types. Comparison between sites identified purely on the basis of high accident numbers and those identified on the basis of their potential for accident reduction, based on RPS analysis, suggest the latter approach can usefully add to existing techniques for identifying appropriate improvement programmes. The report gives a worked example of the scope for introducing cost-effective roadside improvement programmes based on assessing the Net Present Value of their potential to reduce run-off accidents.

An important objective of iRAP was to provide a basis for estimating casualty numbers directly and use these estimates to develop cost effective countermeasure programmes. This was done by "calibrating" a fatality factor for each mode for each country by comparing fatality numbers predicted by the risk model with data available on observed accidents on the network being assessed. Data on observed accidents is generally poor, with location, severity, accident type, and reporting levels all being open to doubt. In addition, estimates had to be made of the proportion of observed accidents that related to the prediction models, as these only covered some of the accident types. Although the accident types modelled represented a large proportion of total accidents in high income countries, the variability of traffic mix and road user behaviour in lower income countries meant that the proportions modelled were harder to judge. Fatality numbers were thus estimated using the formula

Fatalities = RPS x mode flow x country fatality factor x reporting factor

Example of estimation of country fatality factors

Assume that a total of 160 fatalities are reported for the iRAP network in the country and the reporting factor is taken as 1; assume also that % distribution of fatalities by mode is thought to be 50% car occupants, 25% pedestrians, 20% motorcyclists and 5% bicyclists (ignoring other 4-wheel vehicle for simplicity)

	Car occupants	Pedestrian	Motorcyclist	Bicyclist
Estimated total fatalities by mode	80	40	32	8
% fatalities assumed associated with RPS accident types	50	90	40	75
Therefore, number of fatalities expected to be predicted	40	36	13	6
Model predictions if fatality factors = 1	7.4	2.1	0.9	3.4
Fatality factors required for each mode	5.4	17.1	14.4	1.8

Despite the variable quality of observed accident data and the uncertainty in the accident types these data represented, there was some consistency between the values of the fatality factor derived from the data for different countries; this consistency was greater for car occupant fatalities than for the other modes, probably reflecting both less accurate flow data and more variable reporting levels for these other modes. The "reporting factor" was included as an explicit variable so that the assumptions made for different countries could clearly be seen.

A potential countermeasure can be represented directly by changing the state, and therefore the risk factor, associated with one of the variables in the model. This results in a new estimate of the RPS risk score. Potential fatality reductions are therefore represented by

Fatality reduction = (RPS1 –RPS2) x mode flow x country fatality factor x reporting factor

However, in order to utilise these simple principles, a substantive software programme was required to develop rules on which to base countermeasure choices, and to express the outcomes in terms of costs, benefits and Net Present Values of alternative countermeasure programmes.

4.5 Link to Safe System approach

Over the last ten years, road safety strategy in many countries has developed towards the concept of a Safe System. This concept builds on the Zero Vision and Sustainable Safety philosophies developed in Sweden and the Netherlands; the principles underpinning the RAP programmes are closely related to this approach (as described in presentations by Howard and by Lynam to ITE Annual Meeting in Melbourne 2005). The approach is described fully in OECD (2008).

As in EuroRAP, the Safe System seeks a balance between road design, vehicle design and driver behaviour. EuroRAP aims to define what standards are needed from the road system when 4 or 5 star NCAP vehicles are in use, and when drivers comply with traffic laws, particularly in relation to seatbelt wearing and speed choice. Ensuring a "safe" speed for the road is a key part of the Safe System. EuroRAP ratings have been utilised in Sweden to define "safe speeds" for individual roads as the speed at which the road would be rated as 4 star.

The risk curves shown in 4.3 illustrate the road standards and operating speeds that need to be reached to achieve high star ratings with the iRAP model. These are similar to the recommendations for Safe Systems.

4.6 Limitations of current models and potential for improvements

The purpose of the models discussed above was to provide risk estimates based on data that could be collected cheaply over large road networks. For countries with well developed accident data collection systems, the outputs are intended to provide additional information that can help decide road improvement programmes, alongside more traditional investigation techniques. For countries with less well developed data collection and analysis systems, the outputs provide the basis for mass action improvement programmes, which cannot easily be developed from other data sources. The design of the models is thus based on a balance between the accuracy of risk or casualty estimates and the benefit of obtaining a network-wide assessment. In higher income countries, the need for countermeasures should be confirmed using more traditional detailed investigations; in lower income countries, the casualty toll is so large that even large overestimates of potential benefits are unlikely to negate the cost-effectiveness of the proposed countermeasures.

Limitations in the current models and the potential for improvements can be discussed under several headings.

Limited coverage of accident types

The models are limited to estimating safety in relation to run-off, median, and junction accidents. While these accident types make up the large majority of single carriageway fatal accident types, they only represent about half the fatal accidents on motorways. The largest group of fatal accidents not included in the models are shunt accidents; these are not easily affected by road layout measures but could be influenced by measures taken by the road authority to discourage close following. The run-off accidents with which the model predictions are compared are limited to single vehicle run-offs as injuries to occupants of vehicles leaving the road after impacts may have resulted from the earlier impact.

The models predict the risk to car occupants only, and are largely based on data reflecting car to car impacts or single vehicle impacts. Impacts between cars and larger vehicles can be expected to result in more severe injuries to the car occupants. At the same time, accidents in which heavier vehicles impact median barriers or roadside obstacles are likely to result in fewer injuries to their occupants. In principle there is scope to include separate models for occupants of larger vehicles, and also scope to introduce a risk factor in the car occupant models relating to their likelihood of impacting heavier vehicles. In high income countries, where car travel predominates, these additional models are unlikely to have a major effect on the results. In the lower income countries, these accident types are likely to be much more important, particularly where large numbers of passengers may be transported in trailers, but the data on which to base such models is very limited.

Within EuroRAP, there is clearly scope to introduce motorcyclist, pedestrian, and pedal cyclist models along the lines of those used in iRAP, and this is currently being considered. However, these models are less well supported by data than the car-occupant models, and the value of their outputs needs to be considered carefully before they can be used to provide useful conclusions in the context of most high income countries where fatality numbers among these groups are much lower.

Structure of the risk models

The choice of multiplicative models in iRAP leads to a process that is both transparent and easy to use. However, there is no direct allowance for interaction between the factors included in each model. Ideally the number of factors needs to be kept to a minimum to avoid double counting of effects (for example, in curves risk might be influenced by advanced warning signs, road markings, marker posts, sight lines, and transition curves, but these all potentially influence driver awareness in a similar way). At the same time it is desirable to include all the major factors that are expected to affect risk and which might be modified by countermeasures. The focus on individual accident types aims to minimise the use of factors with overlapping effects but it is difficult to assess how far this has been achieved. In some cases, there could be value in introducing additional variables showing interactions between factors, but this would complicate the models considerably. This is partly dealt with by defining some factors (eg junction types, and curve/junction/crossing "quality" factors) as aggregate effects of several possible measures.

The use of rates related to traffic flow introduces several simplifications. Firstly, it assumes linear variation of accidents with flow, which is known not to be the case on some road types and particularly at junctions. Secondly, in several circumstances accident frequency is known to reflect the interaction between flows rather than a single flow figure. This is true at junctions and for impacts between different modes. At junctions some allowance is made for this by using an "intersecting road flow" factor which is not given a risk value directly proportional to flow. For non-car modes, some allowance is provided by assuming risk factors for pedestrian and cyclist flows that again do not vary directly with their flow. But in both cases these are fairly crude assumptions and do not reflect the complexity of the relationships. Until further evidence is available, it is thought the simplicity of the approach outweighs the inaccuracies introduced.

Thirdly, it would be desirable to calculate a flow for the car occupant models that excluded the flow of other 4 wheel vehicles within these models and dealt with the other vehicle occupants using separate models. At present the model reflects risk to car occupants but the flows relate to all motorised vehicles other than motorcycles. However introducing more models covering different modes would be difficult as, for example, the presence of HGVs raises the risk for all other modes, and would thus require variables showing the interaction with several other modes. Although car occupants might be the group most affected, there is already an assumption in the assessments that all cars achieve 4 star occupant protection whereas in practice in low income countries, there is a mixture of vehicle types in the traffic stream including slow moving vehicles and cars in very poor condition. At present it appears more appropriate to recognise the approximation of the current models to the real situation when considering their results, than to try to increase the model complexity.

Improving risk values assumed

The risk values used are based on published research as described above, but in many cases that evidence is fairly sparse, and in some cases conflicting between different studies. Most evidence relates to the effect on all injury accidents whereas the RAP models aim to identify the risk of severe injuries or fatalities. It is known that there are several situations where these effects differ substantially (eg car occupant risk at roundabouts) and for many factors, the influence on fatality risk is not well known.

For several factors (road condition, delineation) conservative values of risk have been chosen as there is no strong evidence of larger effects. Similarly the factors representing "quality" of road features have been given conservative values, as there is some doubt whether the road inspectors can adequately differentiate these factors. In all cases, new evidence could lead to different choices for the risk factor values, and the models are defined so that any changes can be easily incorporated.

One example of an area where risk values are uncertain is the provision of hard shoulders. There is clear evidence (eg Ogden, 1997) that the risk of severe run-off accidents reduces with increases in hard shoulder width up to 2.4m. In principle, if hard shoulder width is further increased there should be yet lower risk of severe run-off injury. But in some countries, and particularly in low income countries where there is a wide range of vehicle speeds, hard shoulders are used as running lanes by slower vehicles (and also by pedestrians). In this case, the run-off risk for these vehicles will be higher but also the risk of conflicts between vehicles moving in and out of these lanes will potentially increase the total number of accidents on the road. Thus while the run-off models should probably still predict low run-off risk, it is arguable that before wide shoulders can be fully evaluated as a measure, an additional model should be introduced to reflect the other conflicts that arise in these layouts. In the short term, a simple way to deal with this might be to add a code reflecting whether the shoulder is used as a running lane, and only allow the lower risk value for run-off accidents when this does not occur.

Classification of junction risk within a few simple categories is particularly difficult, as there a large number of potential basic junction designs, and also potential countermeasures to improve junction safety. The initial junctions types do not for example include staggered junctions, where adjacent three arm junctions can be used to replace a four-leg junction. Angle of junction arms and restrictions on turning movements other than by physical barriers are also not modelled directly. However these omissions have to be balanced against the difficulty of logging a large amount of information at each junction, and again emphasise the need to use the results to highlight potential safety deficiencies that need to be investigated further at individual sites.

Improving understanding of validity of risk and fatality estimates
Paragraphs 2.6 and 3.5 summarise the evidence available from assessments of the validity of comparisons between RPS ratings and observed numbers of fatal and serious accidents. While there is fairly good evidence from some countries of a consistent link between EuroRAP RPS and accident numbers, in other countries this link has not been shown. Even where there is evidence of a strong link, it is obtained by comparing average accident rates for groups of roads with the same RPS. The observed accident rate for an individual road within the group may differ considerably from this average rate. In one sense these differences are not unexpected as it has been clearly stated that EuroRAP ratings are only a partial measure of total accident risk. But it emphasises the need to draw general lessons from the ratings, and to complement assessments for specific sites with local investigation. Despite this, EuroRAP ratings provide a way of looking at consistency of design across a network that appears to mirror accident trends.

There is less evidence to date to support the validity of iRAP ratings although the study by Harwood in the US (section 3.5) provides positive indications. At one level the ratings are producing improvement programmes which are recognised as plausible by local safety engineers (iRAP, 2008). Extensive review of the initial results from the iRAP analyses, while indicating some improvements to risk factor values, has also failed to reveal any major inconsistencies in the results obtained. Good studies of validity based on observed accident data from low- and middle-income countries appear unlikely in the short term due to the quality of accident data in these countries. More might be learned from application of iRAP models to high income countries, both through comparison of RPS ratings with observed accident data, and through direct comparison of fatality predictions with observed data. The iRAP model has been used in pilot studies during 2009 in south-east England, New Zealand, Queensland (Australia) and the US and the results are being assessed in this way.

The country fatality factors which are used to estimate fatality numbers from the iRAP RPS risk scores are recognised to be based on very limited data, as discussed in 4.4. They reflect the combined effect of two generalised, but partly related, national characteristics of the safety problems in each country – first, the non-infrastructure characteristics of the safety problem such as the quality of the vehicle fleet and the behaviour of road users, and second the mix of accident types arising from these factors. What little information is available on which to base these factors arises mainly from national statistics. Where possible, data for roads representing only the inspected network, ie main rural roads with some smaller urban areas, has been used in calibrating the fatality factors. However there remain large differences between the vehicle mix and the accident type mix on different types of road within the iRAP networks, which are not picked up by use of single factors for each mode. Good information on accident types is important as the fatality estimates in iRAP only represent those fatalities associated with the accident types being modelled, eg they exclude car occupant deaths associated with vehicles overturning in the carriageway due to poor driver behaviour. Ideally future work should consider use of different fatality factors for different road types (eg divided and undivided roads). Comparison of the estimated values of the fatality factors with other known safety characteristics in each country (such as seat belt wearing, speeding, vehicle crashworthiness) would also be useful. iRAP surveys in higher income countries, where fuller data is likely to be available, could give useful indications of how the country fatality factors might be improved.

Finally, the programmes proposed from the iRAP ratings reflect the benefits that would accrue from the present traffic flows and traffic composition. This can be taken as a conservative estimate of the future benefits as traffic increases, and estimates can be made assuming traffic growth. But it would also be instructive to use the ratings to assess how accident patterns might change as traffic mix changes – for example, if pedestrian traffic was replaced by motorcycle use or current motorcycle use by car use. This could be done most simply by changing traffic flow levels for future years. But an alternative, or potentially additional, approach would be to modify the country fatality factor to reflect improvement in vehicle crashworthiness and road user behaviour.

4.7 Potential for extending EuroRAP rating to include wider features of iRAP risk models

This report describes two road appraisal models – the original EuroRAP model and the iRAP model. Much of the thinking and the background data behind both models is similar; they evolved differently to meet different purposes. But it was anticipated from an early stage that the EuroRAP car occupant model would be broadened to include likelihood factors. There is also a strong case for adding motorcyclist, pedestrian, and pedal cyclist models to the EuroRAP ratings. But the precision needed for these models to provide useful conclusions in higher income countries is greater than that needed for the lower income countries where the accident risk is so large. At the same time more and more accurate data are available from developed country environments against which to develop such models.

A useful next step, therefore, which is already underway, is to extend the EuroRAP models towards the wider assessment provided by the iRAP models. Much of this is straightforward as there are already many common factors and general consistency between risk factor values. The EuroRAP models would then take on the multiplicative form of the iRAP model. An indication of the way in which an extended EuroRAP model might be used, and the type of results obtained is given in Martin et al (2009). However there may well be a case for retaining some differences between EuroRAP and iRAP, as there already is in some of the features included in EuroRAP assessments in different European countries, in order to reflect the different road environments and the different uses to be made of the results in countries at different stages of safety development and different safety visions.

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Although the author, as Research Co-ordinator for EuroRAP and leader of model development for iRAP, must take responsibility for any deficiencies in the choices made during the model development, the process of model development benefitted from extensive discussions within both EuroRAP and iRAP teams.

In the case of EuroRAP, this included particular contributions from Hans Wahlstrom (initially Swedish National Road Administration, then Swedish Road Traffic Inspectorate), Bo Lonegren (Swedish National Road Administration), Norbert Klassen (German motoring club ADAC), Lluis Puerto (Catalan motoring club RACC), Steve Lawson and James Bradford (EuroRAP).

For iRAP, the final decisions on the models were made jointly by the author, Rob McInerney (initially AARB, later iRAP), Doug Harwood (Midwest Research Institute, Kansas), and Steve Lawson and James Bradford (iRAP).

The methodology described in this report reflects the initial development of the EuroRAP and iRAP models. Some of the choices of risk factors and their values may have been superseded by subsequent revisions in the models currently used in these programmes.

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