iRAP Road Attribute Risk Factors

Roadside Severity - Object

This factsheet describes the road attribute risk factors used in the iRAP methodology for Roadside Severity - Object. Roadside Severity – Object records the nearest object that could result in death or injury to vehicle occupants, motorcyclists and bicyclists if struck. The object recorded is the same as that referred to in Roadside Severity – Distance.

About risk factors

Risk factors, sometimes called crash modification factors (CMF), are used in the iRAP Star Rating methodology to relate road attributes and crash rates. Risk factors (or CMF) are described by the Crash Modification Factor Clearing House as follows:

> *A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.*
>
> *For example, an intersection is experiencing 100 angle crashes and 500 rear-end crashes per year. If you apply a countermeasure that has a CMF of 0.80 for angle crashes, then you can expect to see 80 angle crashes per year following the implementation of the countermeasure (100 x 0.80 = 80). If the same countermeasure also has a CMF of 1.10 for rear-end crashes, then you would also expect to also see 550 rear-end crashes per year following the countermeasure (500 x 1.10 = 550).*

Related documents

This factsheet should be read in conjunction with:

- *Star Rating Roads for Safety: The iRAP Methodology.*
- *Safer Roads Investment Plans: The iRAP Methodology.*
- *Star Rating and Investment Plan Coding Manual.*
- *Road Safety Toolkit (http://toolkit.irap.org).*

Risk factors

Risk factors by road attribute category, road user type and crash type

Roadside Severity – Object	Vehicle occupant run-off	Motorcyclist run-off	Bicyclist run-off
Safety barrier – metal	12	30	30
Safety barrier – concrete	15	25	25
Safety barrier - metal motorcyclist friendly	12	20	20
Safety barrier - wire rope	9	30	30
Aggressive vertical face	55	55	55

Roadside Severity – Object	Vehicle occupant run-off	Motorcyclist run-off	Bicyclist run-off
Upwards slope (15 º to 75º)	45	45	45
Upwards steep slope (>75º)	40	40	40
Deep drainage ditch	55	55	55
Downwards slope	45	45	45
Cliff	90	90	3000
Tree (>=10cm diameter)	60	60	60
Non-frangible sign/ post./pole (>=10cm diameter)	60	60	60
Non-frangible structure/bridge or building	60	60	60
Frangible structure or building	30	30	30
Unprotected barrier end	60	60	60
Large boulders (>= 20cm tall)	60	60	60
None (or object >20m from road)	35	35	35

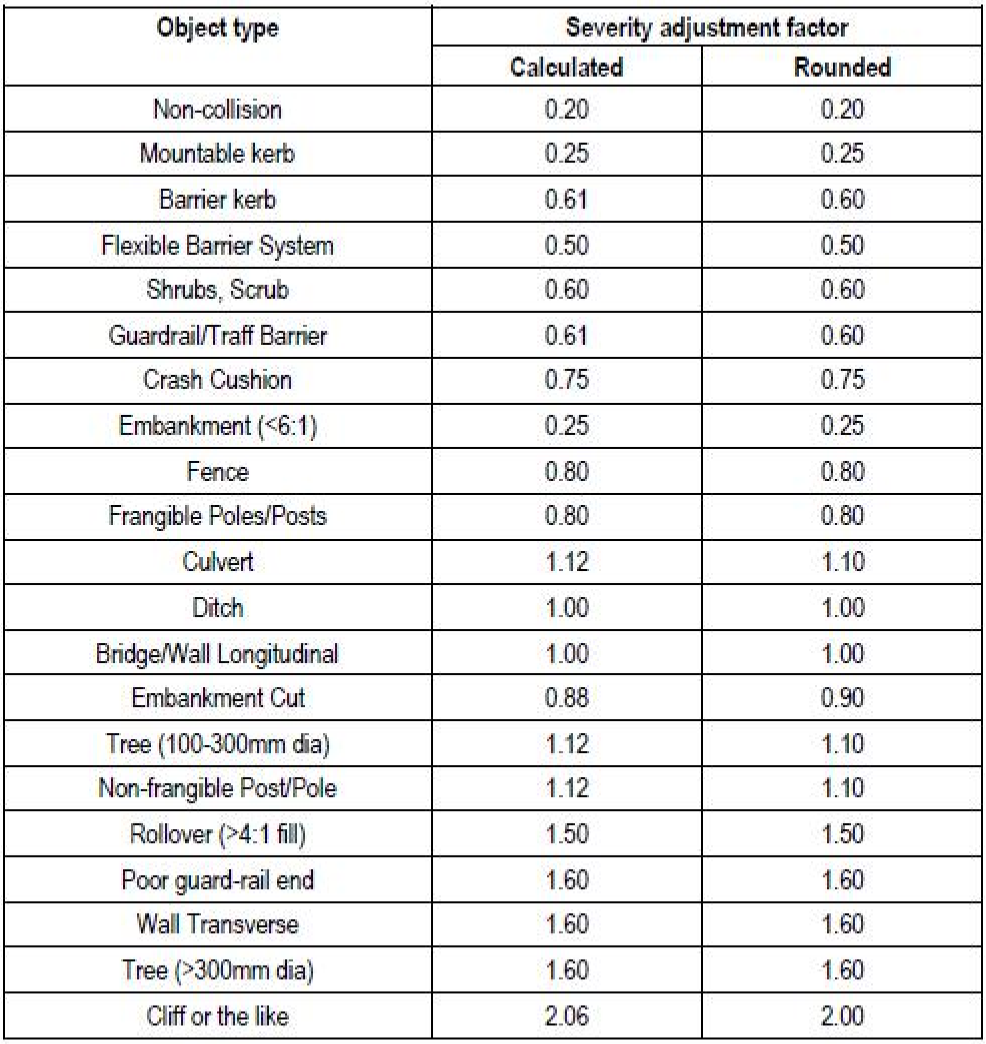
Selection of risk factors

There is a large body of research on this topic which iRAP drew on in the selection of Roadside Severity – Object risk factors. For the component of the iRAP model that relates to the severity of crashes, a reference factor of 100 is set for a head-on crash for vehicles of equal mass (where there are likely to vehicle occupant injuries in both vehicles). All other crash severity-related risk factors are set relative to this score.

The iRAP values have evolved from Version 1 and 2.0 where the relative severity factors for different roadside obstacles were drawn from Appendix A of the 1996 edition of the AASHTO Roadside Design Guide or predecessor documentation.

Veith (2005) provides severity indices for a substantial number of roadside objects and design features. They highlight the high severity of crashes involving trees and poles. In selecting its own values, iRAP has drawn upon primarily Australian, European and US experience and design practices.

Roadside object severity adjustment factors based on Veith (2005)



Object type	Severity adjustment factor	
	Calculated	Rounded
Non-collision	0.20	0.20
Mountable kerb	0.25	0.25
Barrier kerb	0.61	0.60
Flexible Barrier System	0.50	0.50
Shrubs, Scrub	0.60	0.60
Guardrail/Traff Barrier	0.61	0.60
Crash Cushion	0.75	0.75
Embankment (<6:1)	0.25	0.25
Fence	0.80	0.80
Frangible Poles/Posts	0.80	0.80
Culvert	1.12	1.10
Ditch	1.00	1.00
Bridge/Wall Longitudinal	1.00	1.00
Embankment Cut	0.88	0.90
Tree (100-300mm dia)	1.12	1.10
Non-frangible Post/Pole	1.12	1.10
Rollover (>4:1 fill)	1.50	1.50
Poor guard-rail end	1.60	1.60
Wall Transverse	1.60	1.60
Tree (>300mm dia)	1.60	1.60
Cliff or the like	2.06	2.00

<u>Frangible structures</u>

The iRAP values for “frangible building or structure” imply a weak structure such as the simple bus shelter seen in many European cities. Poles and lamp columns may also be frangible and break at the base or fold or collapse over the vehicle when struck.

<u>Trees and poles and other non-frangible objects</u>

Stigson’s work (below) shows the high level of threat (high g-forces for short periods) from bridge piers and, by implication, from large trees.

Other risk factors are also guided by values such as those provided by Stigson et al. (2009).

Table 5 from Stigson et al (2009). Frontal single-vehicle crashes with different collisions partners

Type of crash object	Change of velocity Δ V (km/h)	Mean acc. (g)	Duration (ms)	N
Rigid object	21.3	5.8	102.7	74
Trees	22.1	6.1	101.2	23
Rock face cutting	25.1	6.0	117.5	6
Rocks/boulder	20.7	5.2	107.6	12
Culvert	17.9	4.8	106.2	4
Rigid barrier	21.3	5.7	105.9	9
Bridge pier	19.3	6.7	80.0	1
House wall	16.6	5.8	77.9	6
Embankment	22.5	6.0	106.5	13
Deformable object	15.0	4.0	106.1	51
Deformable pole	15.1	4.0	107.4	30
Deformable guardrail	15.0	4.1	104.3	21
Other	12.9	4.0	92.1	33
Total	17.1	4.8	101.5	158

Cliff

The cliff factor was introduced in Version 2.0 to reflect high severity outcomes irrespective of speed travelled where vehicle recovery and/or crash survivability is expected to be rare.

The very high value of “cliff” for cyclists reflects the fact that the model is replicating a 150km/h impact of a motorised vehicle with a tree. Because the speed risk factors within the cyclist model do not achieve this speed, it is assumed that the bicyclist leaves the road at 35 km/h.

Slopes and drains

Like other objects, slopes and drains are a hazard if they are likely to cause high changes in velocity over a short period of time but not if a “long, slow crash” without any overturning, occupant ejection or severe intrusion of the passenger compartment. Culvert-ends commonly provide severe impacts.

Steel safety barriers – general performance

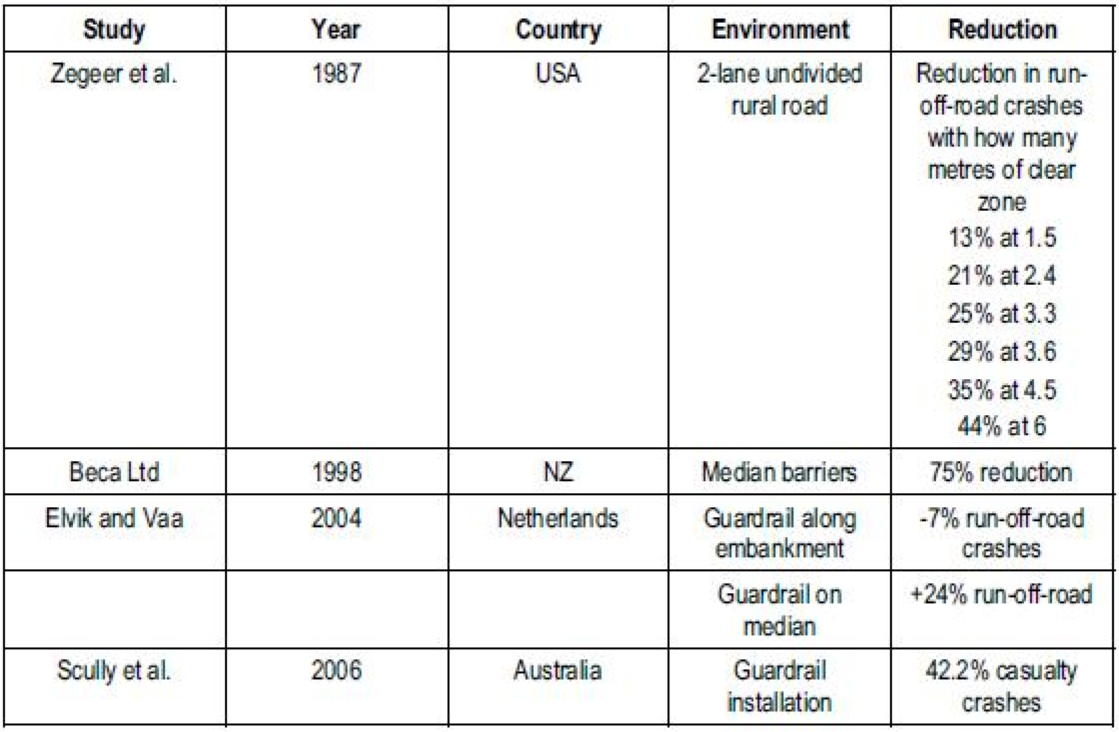
iRAP has chosen to align its value for an impact with a barrier close closely with the motorway “merge lane vs main line” glancing impact. This therefore assumes that most impacts with barriers are relatively acute and the model will not effectively reflect the greater in obtuse impacts.

The iRAP factors for traditional barriers also align a wire rope barrier at 5-10m with a 10m+ clear zone. This indicates a degree of internal consistency.

For 4-wheeled vehicles, there is increasing evidence of the benefits to vehicle occupants of the energy absorbing, protecting, containing and restraining benefits of cable barrier/wire rope fence and this is reflected in the model.

Steel barriers are assumed to perform marginally better than concrete, by virtue of their energy absorbing properties.

Crash reductions from barriers in a range of research (Turner et al, 2010)



Study	Year	Country	Environment	Reduction
Zegeer et al.	1987	USA	2-lane undivided rural road	Reduction in run-off-road crashes with how many metres of clear zone 13% at 1.5 21% at 2.4 25% at 3.3 29% at 3.6 35% at 4.5 44% at 6
Beca Ltd	1998	NZ	Median barriers	75% reduction
Elvik and Vaa	2004	Netherlands	Guardrail along embankment	-7% run-off-road crashes
			Guardrail on median	+24% run-off-road
Scully et al.	2006	Australia	Guardrail installation	42.2% casualty crashes

Turner et al. (2010) comment that most studies only assess the influence of barriers on run-off crashes: “Only one study presented values in terms of reductions in all casualty crashes. The other studies reported reductions in run-off-road crashes. An average reduction of 40% was chosen for the installation of safety barriers across all environments.”

The iRAP risk factors assume that concrete barriers are seen as better for motorcyclists that those of steel (because the former do not have posts). Cable barriers are assumed not to increase the severity of injury to motorcyclists: http://www.me.vt.edu/gabler/publications/TRB-11-3958-Motorcyclist-Barriers.pdf.

Elvik and Vaa (2004) found the reduction was greatest for yielding types of barriers (steel and wire), but that concrete barriers resulted in an increase in casualties. This work could be developed (especially within the Safe System context) to determine the reduction in fatal and serious outcomes from the use of these types of barriers.

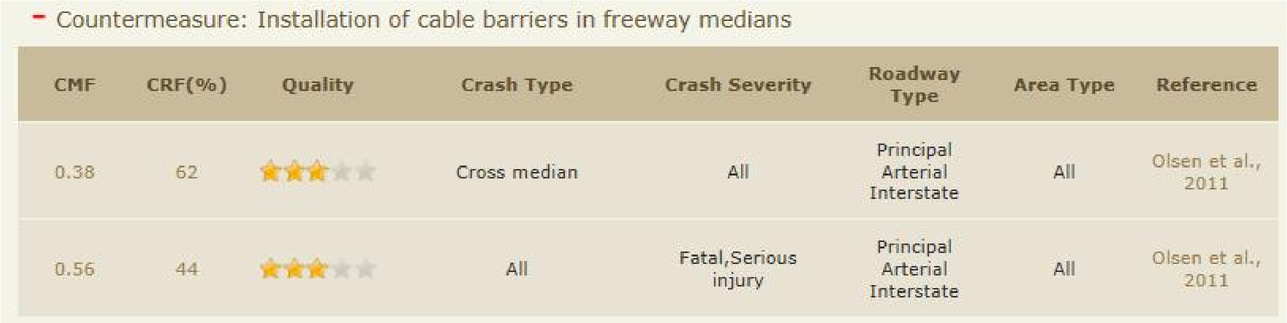
<u>Wire rope barriers</u>

Wire rope safety barriers (a type of flexible barrier) have been used over long lengths of roadway in Sweden, with great success in reducing median crossovers and head-on collisions (Larsson et al. 2003). Wire rope safety barriers deform and re-direct errant vehicles by absorbing the impact energy, significantly reducing severity outcomes. The use of such barriers in Sweden has been highly successful in reducing head-on and run-off-road crashes. The 2+1 system in Sweden has produced large savings in crashes, with a reduction in fatalities of up to 90%.

The Version 3 base value for wire rope barrier is a risk factor of 9, assuming a better performance than other barriers and better than a 10m+ clear zone.

Work from elsewhere has shown crash modification factors (CMFs) for these installations as good. CMFs of 0.38 cross-median and 0.56 all fatal & serious injury. See the excerpt below from the Crash Modification Factor Clearinghouse.

Cable barrier crash modification factors – excerpt 1 (CMF Clearing House, 2013)



− Countermeasure: Installation of cable barriers in freeway medians

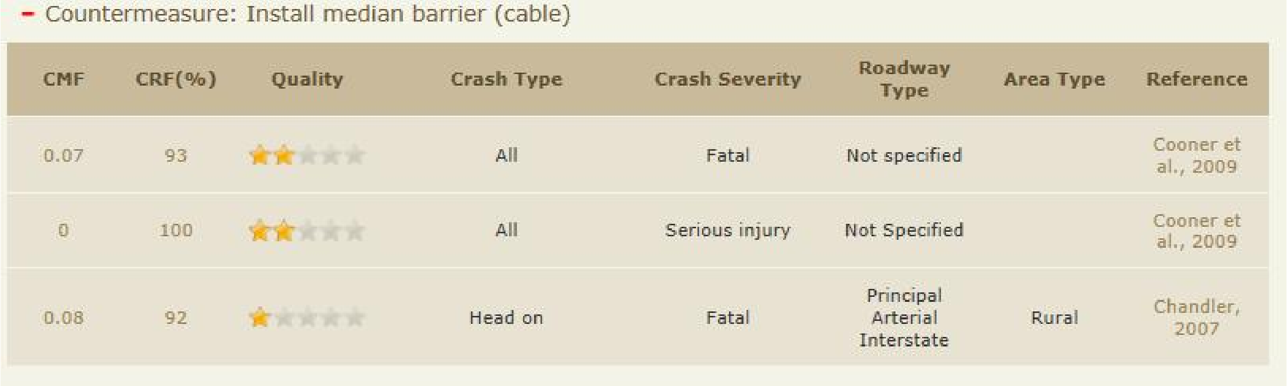
CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.38	62	★★★☆☆	Cross median	All	Principal Arterial Interstate	All	Olsen et al., 2011
0.56	44	★★★☆☆	All	Fatal,Serious injury	Principal Arterial Interstate	All	Olsen et al., 2011

Cooner (2009) has provided exceptionally low crash modification factors of 0.07 and 0.08 – risk factors that are approaching zero for likelihood of severe injury for vehicle occupants:

> *Cable barriers are performing extremely well and have had very few cases of penetration unless there were nonstandard impact conditions. Researchers believe that the cable barriers are functioning according to their intended design and are restraining vehicles that impact them in fashions similar to NCHRP 350 crash-testing guidelines. The installation of cable barriers has produced significant benefits with a reduction of 18 fatalities and 26 incapacitating injuries in the first full year.*

Again, note that Cooner's results particularly highlight their application as a median barrier although Turner et al. (2010) also show good run-off results from other studies.

Cable barrier crash modification factors – excerpt 2 (CMF Clearing House, 2013)



− Countermeasure: Install median barrier (cable)

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.07	93	★★☆☆☆	All	Fatal	Not specified		Cooner et al., 2009
0	100	★★☆☆☆	All	Serious injury	Not Specified		Cooner et al., 2009
0.08	92	★☆☆☆☆	Head on	Fatal	Principal Arterial Interstate	Rural	Chandler, 2007

<u>iRAP barrier values compared with Australian research</u>

For barriers, iRAP has compared its own values with those used elsewhere and in particular those in Appendix B, Table B1 of the Austroads report by Jurewicz et al. (2012) which suggests a lower benefit for barriers. By choosing a greater benefit for the barrier countermeasure, iRAP avoids overstating the severity of those crashes potentially present in some studies in instances where barriers are recorded as an impact on the police crash report form when they may have been a purely incidental part in the overall crash and not the "main" or most severe impact. Barriers do show a degree of "aggressiveness" and although they are of course not always a complete crash protection solution, in some crashes they are recorded as a struck object when they may only be an incidental part of the crash.

In some cases it may be there is a difference between severity indices in such as those provided by Austroads and CMF factors presented in many "before and after" studies because the latter sites are self-selecting for the analysis. They may therefore be higher risk and show greater benefits when treated.

There is also a potential association of the distance-to-object in that barriers are typically closer to the carriageway than other objects.

<u>Other situations</u>

iRAP risk factors are relatively high on steep upward slopes where rollover is likely. These factors are justified on the basis that in many situations in Low- and Middle-Income Countries such manoeuvre will involve at least partial ejection of vehicle occupants.

Barrier ends where spearing or launching of a vehicle may occur are classified as hazards.

Background research and model development

Lynam (2010) explained the rationale behind the risk factor selection in the early EuroRAP and iRAP work. 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 crash 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 crash rate by average roadside recovery distance (that is, 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 crashes of 25% and a distance of 20 feet (6.6m) with a reduction of 50%.

Knuiman et al (1993) found that median crash rates and severity decline rapidly when the median width exceeds about 25 feet (7.6m). Meewes and Kuler (2001) compared run off crash rates for roads with different clearance distances on either side. This study suggested the following reductions in crash 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 crashes 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 be 3.5m (regional two lane road), 7m (federal two-way road, and 10m (motorway).

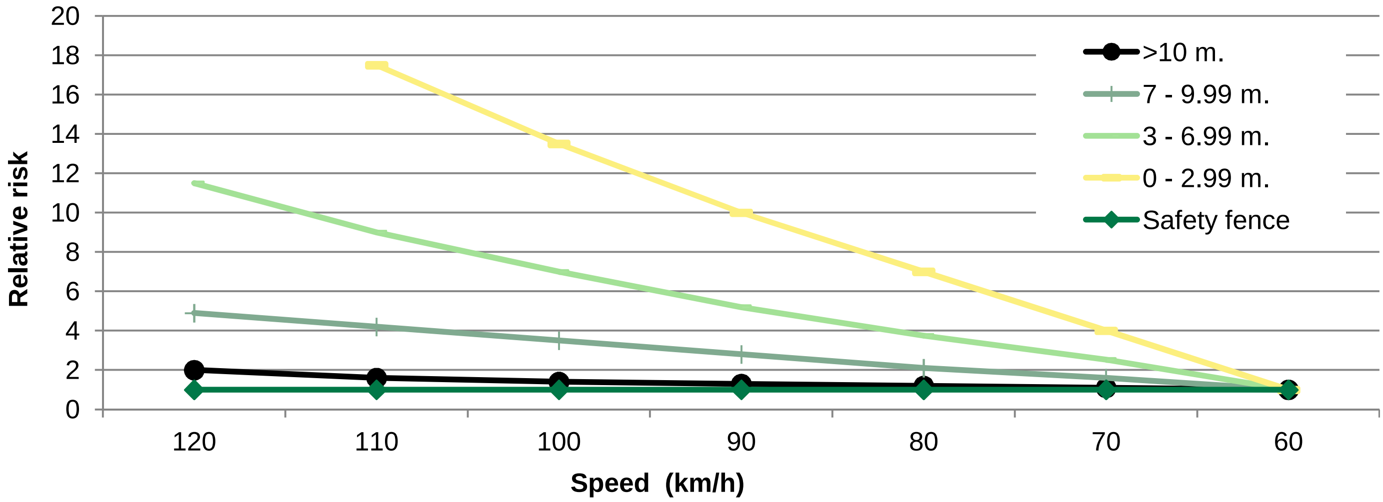
Elvik and Vaa (2004) conclude that increasing the safety zone from 1m to 5m reduces injury crashes by 22%, and increasing from 5m to 9m reduces injury crashes by 44%. They suggest that flattening the embankment slope from 1:3 to 1:4 reduces crashes by 42%, and from 1:4 to 1:6 by 22%. The same authors conclude that guardrails on embankments reduce run-off-road fatalities by 44%, but run-off crashes 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 cliff risk factor was introduced in the iRAP model to reflect high severity outcomes irrespective of speed travelled where vehicle recovery and/or crash survivability is expected to be rare.

In earlier versions of the iRAP model, a distinction was made between the relative risk of injury striking objects less than 3m from the edge line, from 3m to less than 7m, from 7m to less than 10m, and greater than 10m. This was compared with a baseline risk of striking a safety fence, as shown in the figure below.

Early iRAP model risk factors for run-off by speed



In earlier versions of the iRAP model, the elements of the model were applied as shown in table below, to the vehicle occupant, motorcyclist and bicyclist models. The model did not distinguish between the crash protection characteristics of different hazards other than as shown in the table. This measure therefore combined some element of severity with likelihood.

Risk factors in earlier versions of the iRAP model

Roadside condition	Vehicle occupant	Motorcyclist	Bicyclist
Safety barrier	1.75	2.5	1.0
Cut	1.75	1.75	1.0
Deep drainage ditches	5.0	5.0	5.0
Steep fill embankment slopes	5.0	5.0	5.0
Distance to object 0-5m	5.0	5.0	5.0
Distance to object 5-10m	3.8	3.8	3.8
Distance to object >10m	1.0	1.0	1.0
Motorcyclist friendly barrier	1.75	1.75	1.0
Not record (low speed area)	0.0	0.0	0.0
Cliff	10	10	10
Safety barrier (concrete (CEN)) *	1.75	NA	NA
Roadside 0-3m *	6.0	NA	NA
Roadside 3-7m *	4.0	NA	NA
Roadside 7-10m *	2.0	NA	NA
Roadside > 10m *	1.0	NA	NA

** These attributes were present in the European application of the model and therefore only to the vehicle occupant element.*

Primary references

The following publications are the primary references used in the selection of the iRAP road attribute risk factors. A complete list of citations is available in: *iRAP Road Attribute Risk Factors: Full Reference List.*

Elvik, R, Hoye A, Vaa, T, and Sorensen, M. (2009). *The Handbook of Road Safety Measures, Second Edition (2009)* Emerald Group Publishing Limited. ISBN 978-1-84855-250-0.

Lynam, D (2012). Development of Risk Models for the Road Assessment Programme. RAP504.12 and TRL Report

CPR1293, Published by iRAP and TRL and available at: http://www.trl.co.uk and at http://www.irap.org.

Mak, K. and Sicking, *D. (2003). Roadside Safety Analysis Program* – Engineer's Manual. Transportation Research Board (TRB) National Cooperative Highway Research Program (NCHRP) Report 492. ISBN 0-309-06812-6.

Turner, B. Steinmetz, L., Lim, A. and Walsh, K. (2012). Effectiveness of Road Safety Engineering Treatments. AP-R422-12. Austroads Project No: ST1571.

Turner, B., Affum, J., Tziotis, M. *and Jurewicz, C. (2009). Review of iRAP Risk Parameters*. ARRB Group Contract Report for iRAP.

Turner, B., Imberger, K., Roper, P., Pyta, V. and McLean, J. (2010). *Road Safety Engineering Risk Assessment Part 6: Crash Reduction Factors*. Austroads AP-T151/10. ISBN 978-1-921709-11-1.

University of North Carolina Highway Safety Research Center and U.S. Department of Transportation Federal *Highway Administration (2013). Crash Modification Factors* Clearing House: http://www.cmfclearinghouse.org/.

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