SWOV Fact sheet

Run-off-road crashes

Summary
In the Netherlands, one-third of all fatalities and one-sixth of all seriously injured are the consequence of run-off-road crashes. The outcome of run-off-road crashes is relatively severe, one fatality in five seriously injured, which is twice the average in the Netherlands. Serious run-off-road crashes often occur in bends, and the majority is registered on 80km/h roads. Measures to prevent run-off-road crashes are a correct and predictable road layout, and a forgiving layout with rumble strips, hard strips and semi-hardened road shoulders. With respect to vehicles, Electronic Stability Control (ESC) turns out to be quite effective. If vehicles do end up on the shoulder, sufficiently wide obstacle-free zones should prevent a collision with obstacles. If this is not feasible, the obstacles should be shielded. Audits and inspections, giving safety scores to provincial roads and shoulders and developing crash models for this type of road should help select and prioritize measures, also with respect to forgiving shoulders.

Background and content
One of the Sustainable Safety principles is the forgiveness of the road environment (see also SWOV Fact sheet *Background of the five Sustainable Safety principles*). This 'physical' forgiveness is important for preventing run-off-road crashes and reducing the effect when they occur. This fact sheet will discuss the scale of the problem of run-off-road crashes, their characteristics and possible solutions. Run-off-road crashes are crashes involving obstacles (often against trees) as well as single crashes, such as turning over and landing in the ditch (see also SWOV Fact sheet *Cars submerged in water*). Main attention in this fact sheet will be focused on road shoulders alongside 80km/h roads. The majority of serious[1] run-off-road crashes occurs in these roads.

What is the size of the problem?
In 2009, circa 190 fatalities occurred in circa 180 run-off-road crashes in the Netherlands. In the period 2005-2009, an annual average of almost 220 fatalities and 840 seriously injured were registered in run-off-road crashes (*Table 1*). This is almost one-third of all road fatalities and seriously injured registered in the Netherlands. *Table 1* also shows that these casualties were the result of circa 200 fatal run-off-road crashes and 760 run-off-road crashes with seriously injured.

	2005	2006	2007	2008	2009	Annual average in 2005-2009	Share of total in NL
Fatalities	258	205	199	228	192	216	31%
Seriously injured	1,021	872	832	783	672	836	16%
Fatal run-off-road crashes	236	185	186	207	176	198	30%
Run-off-road crashes with seriously injured	1,021	872	832	783	672	758	16%

Table 1. *Registered numbers of serious run-off-road crashes in 2005-2009, including the number of casualties. The run-off-road crashes were selected with respect to five manoeuvres: submersion in water, other single crashes, collision with lamppost, collision with other roadside obstacles and collision with tree and other fixed obstacles. The figures are based on all police-registered crashes and relate to all modes of transport. The share is related to all registered serious road crashes in the Netherlands (Ministry of Infrastructure and the Environment; Dutch Hospital Data (DHD)).*

The share in fatal run-off-road crashes initially rose from 24% of all registered crashes in 1987 to 34% in 2002 (percentages not included in table), yet this share again slightly decreased to 30% in 2009.

[1] A serious crash is a crash with a fatality or serious road injury. A serious road injury is a casualty with an injury rate of MAIS 2 or higher. The numbers of serious road injuries in run-off-road crashes were registered for the years 1993 to 2009.

One fatality occurs in five serious run-off-road crashes; this proportion is twice as high compared to all crashes in the Netherlands (not included in table).

Which modes of transport are involved in run-off-road crashes most frequently?
Passenger cars are involved in more than 70% of fatal run-off-road crashes (*Table 2*). In addition, many fatal run-off-road crashes occur with motorcycles (11%). Run-off-road crashes with serious road inuries mainly involve mopeds (12%) and motorcycles (11%), in addition to passenger cars (62%). Lorries are not frequently involved in run-off-road crashes and only one serious run-off-road crash involving a bus occurred between 2005 and 2009. It should be taken into account that the registration rate of cyclist only run-off-road crashes is extremely low.

Mode of transport	Fatal run-off-road crashes		Run-off-road crashes with serious road injuries	
	Number	Share	Number	Share
Bicycle	6	3%	26	3%
Light moped	2	1%	22	3%
Moped	9	4%	97	12%
Motorcycle/motor scooter	23	11%	88	11%
Passenger car	155	72%	521	62%
Delivery van	13	6%	57	7%
Lorry	4	2%	9	1%
Bus	0.2	0%	1	0%
Other	4	2%	12	1%
Total	**198**	**100%**	**758**	**100%**

Table 2. *Average annual number of registered run-off-road fatalities and serious road injuries in the period 2005-2009, itemized by mode of transport. The share is related to the total of modes of transport involved in a run-off-road crash (Ministry of Infrastructure and the Environment, DHD).*

On which type of road do most run-off-road crashes occur?
In absolute terms, most run-off-road crashes are registered on 80km/h roads: 81 fatal crashes and 242 crashes with one or more serious road injuries per year in the period 2005-2009 (see *Table 3*). The 50km/h road comes next with 33 fatal crashes and 202 crashes with one or more serious road injuries. When we relate the run-off-road crashes with all fatal crashes on the types of road concerned, 36% of run-off-road crashes occur on 80km/h roads, compared to only 17% on 50km/h roads. This share is 40% on 120km/h roads and almost 50% on 60km/h roads. In absolute terms, the problem here is less substantial than on 80km/h roads.

Run-off-road crashes often occur in bends. As such, one-third of the fatal run-off-road crashes (34%), as well as of run-off-road crashes with seriously injured (33%) are registered as having occurred in a bend (see *Table 4*). Recent in-depth research into run-off-road crashes actually indicated that 53% of the serious run-off-road crashes studied (n=86) occurred in, or immediately following a bend (Louwerse et al., 2012). This indicates that the effect of a bend on the occurrence of a run-off-road crash seems to be underestimated according to the registration.

Relatively often, a crash in a bend, on the other hand, is found to be a run-off-road crash. Of the total number of registered fatal crashes in a bend, circa two-thirds (64%) are run-off-road crashes. For run-off-road crashes with serious road injuries, the share is 50%. These shares do not significantly differ between urban or rural areas (not included in the table).

Urban or rural	Speed limit	Fatal run-off-road crashes		Run-off-road crashes with serious road injuries	
		Number	Share compared to all crashes	Number	Share compared to all crashes
Urban	50 km/h	33	17%	202	9%
	70 km/h	3	36%	7	14%
Rural	60 km/h	27	47%	75	27%
	80 km/h	81	36%	242	26%
	100 km/h	10	32%	33	30%
	120 km/h	20	40%	71	37%
Total urban and rural		**198**	**30%**	**758**	**16%**

Table 3. *Average number of annually registered run-off-road crashes with fatalities and seriously injured in the period 2005-2009, itemized by speed limit. The share is related to all types of crashes on the specific road type. The figures are based on all police-registered crashes and relate to all modes of transport ((Ministry of Infrastructure and the Environment, DHD).*

Road situation	Fatal run-off-road crashes		Run-off-road crashes with seriously injured	
	Number (share)	Share compared to all crashes	Number (share)	Share compared to all crashes
Bend	67 (34%)	64%	251 (33%)	50%
Straight road	109 (55%)	33%	392 (40%)	19%
Intersection and other	21 (11%)	10%	115 (15%)	5%
Total run-off-road crashes	**198 (100%)**	**30%**	**758 (100%)**	**16%**

Table 4. *Average number (and share) of annually registered run-off-road crashes with fatalities and seriously injured in the period 2005-2009, itemized by road situation. The share in the separate column is related to all crashes at the specific road situation. The figures are based on all police-registered crashes and relate to all modes of transport ((Ministry of Infrastructure and the Environment, DHD).*

What are the causes of run-off-road crashes?

Generally speaking, two types of run-off-road crashes can be distinguished: the 'controllable' run-off-road crashes and the 'uncontrollable' run-off-road crashes. 'Controllable' run-off-road crashes (incidents) develop, for example, when a driver is distracted or fatigued and therefore loses direction. In these cases the vehicle crosses the edge marking and in part lands on the road shoulder. If the roadside has a safe layout, it offers the driver the opportunity to steer the vehicle out of the road shoulder and back onto the road in a controlled manner. This requires a hard road shoulder directly alongside the road and a level transition between shoulder and carriageway. If this is not the case, the incident may well result in a crash. 'Uncontrollable' run-off-road crashes mainly occur in bends, at high speeds or when the driver is under the influence of alcohol and/or drugs. These are mostly real crashes, in which a vehicle crosses the edge marking and goes into the road shoulder entirely. Measures warning a driver of crossing the edge marking are generally not effective in these cases. Once a vehicle is in the road shoulder, the risk is high that the vehicle turns over (especially when the shoulder is soft), hits an obstacle, or lands in a ditch.

In the period 2010-2011, SWOV conducted two in-depth studies to gain further insight in causes and effects of run-off-road crashes (Davidse, 2011; Davidse et al., 2011). Various crash factors were found to have contributed to these causes and effects. The most frequent human-related crash factors are: distraction during the driving task (28%), fatigue (14%), alcohol (13%) and speed (too high for the conditions) (23%). Most road-related factors are characteristics that should have prevented vehicles running off the road: hard strips being too narrow or absent (10%) and semi-hard shoulders (12%).

With 42%, too narrow an obstacle-free zone (the road characteristic meant to reduce the severity of a run-off-road crash) is by far the most important crash factor in run-off-road crashes. Predictability of the road course is also important (see also SWOV Fact sheet *Predictability by recognizable road design*). An unexpected and non-signposted sharp bend may result in a driver not reducing speed, which may cause him to run off the road. The in-depth studies showed that one in seven run-off-road crashes occur in or directly following a bend with too narrow a curve radius, with too narrow an obstacle zone and insufficient signposting or beacons (Louwerse et al., 2012).

What is the effect of rumble strips and hard strips?

If a vehicle should go off the carriageway in a more or less controlled manner, a combination of rumble strips and hard strips may prevent a vehicle from running off the road. Rumble strips are longitudinal (traverse) strips on the road surface or in the edge markings. This latter is called rumble strip edge marking. Driving over rumble strips causes a sound (acoustic feedback) and/or vibration (haptic feedback) that alerts the driver. A hard strip alongside the carriageway is intended to make it possible for drivers to steer back onto the road way. If such a hard strip is made of asphalt, the rumble can be milled or rolled into the strip itself, or be constructed in the shape of thermoplastics. No research has been carried out into rumble strips in the Netherlands; in the United States rumble strips have proved to be effective. The number of run-off-road crashes on rural single carriageway roads was reduced by 15% and the number of fatal run-off-road crashes and run-off-road crashes with serious road injuries was reduced by 29% (Torbic et al., 2009).

What is the effect of a good road shoulder surface?

If a vehicle runs off the road, two measures are necessary to enable the driver to steer the vehicle back onto the road. The first measure is to ensure the smallest possible difference in height between the carriageway (road surface) and the road shoulder. This prevents the wheels of the vehicle being subjected to unexpected forces when the vehicle is steered back onto the carriageway. The second measure is to lay grass-concrete bricks (concrete bricks with hollow spaces), plastic slabs, or gravel alongside the road. This keeps the vehicle more controllable when it lands in the shoulder. The colour and/or texture of the (semi-) hard shoulder needs to be different from the carriageway surface to prevent the road looking wider than it actually is. In the Netherlands, various types of (semi-)hard shoulder were tested in a number of projects. In the Province of Overijssel, for example, grass-concrete bricks were tested best with respect to bearing capacity, management and maintenance (Overkamp, 2004).

International studies have investigated the road safety effects of shoulder surfacing. In Australia, Ogden (1997) found that a hardened shoulder strip of 0.6-0.8 m alongside highways (comparable to the Dutch single carriageway through roads), resulted in a more than 40% decrease in the number of run-off-road injury crashes. Some other studies found smaller reductions. No research into the road safety effect of (semi-)hard shoulders has been carried out in the Netherlands. In calculations SWOV uses a 20% effect for rural single carriageway through-roads and distributor roads (Wijnen et al., 2010). Schoon (2003) determined the cost-effectiveness ratio of (semi-)hard road shoulders on 1 : 1.6 which makes it a cost-effective measure.

How should obstacle-free zones be designed?

The obstacle-free zone is meant to enable the road user to safely come to a halt alongside the road when he keeps to the speed limit in force if it is no longer possible to steer the vehicle back onto the road. No obstacles that can cause severe damage to a vehicle and/or injuries to car occupants are allowed within this zone (CROW, 2004). In the obstacle-free zone, so-called crashworthy roadside objects are allowed, such as thin-walled aluminum lampposts and emergency telephones which give way in a collision with a passenger car. The road shoulder may have a side slope, provided it is not too steep. Experimental research and mathematical simulations carried out by SWOV indicated that downward roadside slopes must be no steeper than 1:6 and for upward roadside slopes no steeper than 1:2 (Schoon, 1999). The slope also needs to be rounded off at the bottom and top.

For all rural road types there are guidelines for the width of the obstacle-free zone *(Table 5).* These zones consist of a supportive shoulder that should enable the road user to steer the vehicle back onto the carriageway or to safely bring it to a halt. The widths of the obstacle-free zones for different road types were determined on the basis of SWOV research (Schoon & Bos, 1983) and international studies. The obstacle-free zone should preferably have the standard width; for the different road types this varies between 2.5-13 m. The effect of widening the obstacle-free zone from 1-2 m to 6 m alongside an 80km/h road is estimated to reduce the number of run-off-road crashes with circa 80% (Wijnen et al., 2013).

Type of road	Standard
Rural access roads – 60 km/h	2.5 m
Rural distributor roads – 80 km/h	6 m
Single carriageway through roads – 100 km/h	10 m
Dual carriageway motorways – 100 km/h	10 m
Dual carriageway motorways – 120 km/h	13 m

Table 5. *The required widths of obstacle-free zones for various road types in the Netherlands (CROW, 2004; Dubbeldam, 2006).*

For example, if the obstacle-free zone alongside a distributor road with a speed limit of 80 km/h is insufficiently wide and the road's function is in accordance with its use, it may be considered to reduce the speed limit to, in this case, 60 km/h (Dijkstra, 2010). *Table 5* shows that this allows for a difference of 3.5 m in required width. The limit being lower than usual for the road type should be supported by speed-reducing measures. A cost-benefit analysis, for instance using VVR-GIS, can be used as a basis for such a decision. VVR-GIS is an instrument for the calculation of effects, costs and benefits of local and regional road safety measures.

What to do with 'danger zones' alongside the carriageway?
Many roads have a so-called danger zone alongside the carriageway, for example a line of trees, a steep slope or a ditch, or a (lamp) post within the required width of the obstacle-free zone. Preferably the danger zone should first be removed. If this is no option, steel or concrete safety barriers are constructed alongside motorways (Heijer et al., 1994). The standard barrier constructions on motorways (performance category H2, see *Table* 6) are capable of redirecting lorries and buses up to circa 13 tons. For redirecting heavier lorries (up to 50 tons), extremely strong constructions are required. These are only used for engineering works, for instance for a fly-over across an underlying road or railway when running off the road causes extra dangers for third parties.

Road category	Maximum speed	Protection occupants	Protection third parties
National through road (motorway)	120 km/h	H2	H2
Rural through road (motorway)	100 km/h	H1	H2
Distributor road	80 km/h	N1 (impact angle 20 degrees)	N1 (only applied in exceptional cases)

Table 6. *Performance category barrier constructions by road category (CROW, 2004).*

In addition to performance category, the safety category and the so-called working width are also important when selecting a particular barrier construction. The safety category is indicated by an ASI-value (Acceleration Severity Index), the measurement for the impact encountered by an occupant of the car during a collision. The lower the ASI, the smaller the impact, the greater the safety result. For this reason, safety category A with ASI<1 is most often required. The ‘working width' is a measurement for the extension of a safety barrier during a crash; it determines the distance to the object to be shielded. Alongside 80km/h roads with trees close to the road, only safety barriers with a limited working width (e.g. < 1 m) should be used.

Obstacle guards are constructed alongside motorways to shield freestanding obstacles; these are impact attenuators (RIMOBs) in the Netherlands. A RIMOB is capable of guiding passenger cars with speeds up to 100 km/h relatively safely (Van der Drift, 1992). A RIMOB is also available for speeds up to 80 km/h.

At single lane carriageways, safety barriers are only placed near engineering works such as fly-overs and rarely alongside regular road stretches. From the viewpoint of recognizability, the standard safety barrier is undesirable - also on engineering works - because this would suggest associations with motorways (see also SWOV Fact sheet *Predictability by recognizable road design*). The WICON (wheel catching construction) lacks this association, due to its limited height. Moreover, the WICON catches the vehicle during a crash, thus preventing the car from bouncing back and colliding with oncoming vehicles. Due to its high cost, the WICON has been constructed at only four locations in the Netherlands.

Another type of safety barrier is the cable barrier. This type is increasingly used in countries such as Sweden (Bergh & Carlson, 2005), Australia, New-Zeeland and the US. In these countries, the cable barrier is especially used as a physical driving direction separator on a narrow median. The cost is circa half that of the standard safety barrier and about a quarter of the price of the WICON (Schoon, 2003). This type of safety barrier is less often used to shield fixed obstacles, because of its increased working width of 2.5 to 4 m. However, a number of manufacturers supply a type with a working width of no more than 1.3 m (Highways Agency, 2012)[2], so that the cable barrier may also be applied for shielding trees that stand close to 80km/h roads.

The CROW Platform "Forgiving roads and road environments' is currently considering alternative barrier constructions at a lower price, in particular to shield lines of trees, ditches and steep slopes alongside older 80km/h roads. Considering the minor share of run-off-road crashes with lorries on this type of road, the construction of safety barriers with standard redirection power (performance category N1) does not constitute a problem. If a safety barrier is positioned close to the single carriageway road, the impact angle is expected to be smaller. According to the European NEN-EN 1317-2 norm, at an impact angle of 8 or 15 degrees respectively, a low redirection power may even be sufficient (performance category T1 or T2 respectively; NEN, 2006). This would result in a cheaper safety barrier that also fits in better with the road design of 80km/h roads. However, a study of the impact angle on Dutch 80km/h roads should first indicate whether the impact angle is indeed this small.

It should be taken into account that certain measures to increase the safety of road shoulders, such as safety barriers and aluminum lampposts, benefit occupants of passenger cars, but are disadvantageous for motorcyclists and (light) moped riders. Motorcyclists benefit most from an obstacle-free zone, yet if barriers are needed (for instance in bends), underrun protection is required (CROW, 2003).

What can vehicle technology do for run-off-road crashes?
Lack of space on 50km/h roads, where many serious run-off-road crashes occur, makes it even more difficult to create safe road shoulders here than on rural roads. The risk of serious crashes on roads without forgiving road shoulders can especially be reduced when drivers are forced to keep to the speed limit, wear seat belts and are prevented from driving off the road. For vehicles, new systems are being developed to support car drivers. Electronic Stability Control (ESC) has proved to be particularly effective in preventing run-off-road crashes: 30% to 62% fewer fatal single-vehicle crashes. From 2014, all new passenger cars must be equipped with ESC as a standard. Other technical developments will also (be able to) play an important role in the prevention of run-off-road crashes; for example, seat belt reminders, Intelligent Speed Assistance (ISA) and Lane Departure Warning Systems. It is expected that eCall, a system automatically informing the incident room about a crash, will become compulsory for all new vehicles in 2015. Especially in single-vehicle crashes, such as run-off-road crashes, this system can accomplish faster emergency assistance. More information about these types of systems can be found in the SWOV Fact sheets *Seat belt reminders*, *Intelligent Transport Systems (ITS) and road safety*, *Intelligent Speed Assistance (ISA)* and *Electronic Stability Control (ESC)*.

Which initiatives focus on improving road shoulder safety?
In the Netherlands as well as in Europe, various initiatives focus on making road shoulders more forgiving. For the state road network, audits and inspections have been compulsory since 2011 (see also SWOV Fact sheet *Road Safety Audit and Road Safety Inspection*) also for motorways and 80km/h roads (Schepers, 2008).

At European level, EuroRAP (European Road Assessment Programme) developed a Road Protection Score (RPS) that gives safety scores to roads, including the road shoulder (Lynam, 2012). In 2007, the Royal Dutch Touring club ANWB used this RPS to assess state roads in the Netherlands and did

[2] For instance, 'Brifen 4 rope safety barrier' with performance category N2, working width category W4, support distance 1.2 m, ASI category - A, and tested in conformity with EN1317.

the same in 2012 for provincial roads in the Dutch provinces of Gelderland and Overijssel. In 2013, roads in all other provinces were assessed. (Van den Hout, 2013; Dietzel & Dwarshuis, 2014) SWOV will assist a number of provinces in translating the RPS results into concrete measures.

As run-off-road crashes are of widespread occurrence, they can only be prevented by constructing forgiving road shoulders pro-actively and extensively. For this purpose, SWOV is developing crash models (Accident Prediction Models) for 80km/h distributor roads (Schermers & Duivenvoorden, 2010), that can assist in selecting and prioritizing the correct measures.

Conclusions

In the Netherlands, one-third of all fatalities and one-sixth of all serious road injuries are registered as a consequence of run-off-road crashes. With one fatality in every five crashes, twice the average in the Netherlands, the outcome of run-off-road crashes is relatively severe. The majority of serious run-off-road crashes is registered on 80km/h roads. One-third of all registered run-off-road crashes occurs in a bend and, vice versa, a crash which happens in a bend is relatively often a run-off-road crash: two-thirds of the fatal crashes and half the crashes involving seriously injured.

Recent in-depth research indicates that in one in ten run-off-road crashes the hard strip did not comply with the directives; in about the same number of crashes the (semi-)hard shoulder did not comply. These road characteristics are intended to prevent vehicles steering off the road. In one in seven run-off-road crashes, the obstacle-free zone, the road characteristic which is to limit the severity of a run-off-road crash, turned out to be insufficiently wide. The research also indicated that one in seven run-off-road crashes occurs in or immediately after a bend with too narrow a curve radius, too limited an obstacle zone, and signposting and beacons not complying with the directives.

Measures that may prevent running off the road are a correct and predictable road layout, providing rumble edge markings, hard strips and (semi-)hard road shoulders. With respect to vehicles, the Electronic Stability Control (ESC) turns out to be effective. Sufficiently wide obstacle-free zones can prevent collisions with obstacles on the road shoulder. If this is not possible, the obstacles need to be shielded by a safety barrier or a RIMOB. Research should indicate if a more lightweight, and thus cheaper safety barrier can be used for screening trees, ditches or steep slopes alongside 80km/h roads.

In the Netherlands, as well as in Europe, various initiatives focus on making road shoulders more forgiving. Audits and inspections have become obligatory for the state road network since 2011. The ANWB have given safety scores to all provincial roads and road shoulders in 2013. SWOV is developing crash models for this type of road, for the purpose of prioritizing measures.

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