

Addressing Run Off Road Safety

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ABSTRACT

Run off road events are frequent and can result in severe consequences. The reasons for leaving the road are numerous and the sequence the car is exerted to differs in most events. The objective of this study is to identify different situations and mechanisms both in respect to accident avoidance and occupant protection and to present test methods addressing the different identified mechanisms of run off road occupant safety.

Mechanisms and influencing factors are identified using statistical and in-depth crash data as well as driving data. There are a number of reasons for leaving the road; driver fatigue, driver distraction and inadequate speed in relation to the traffic situation to mention a few. An outline of principle test methods for evaluating technology assisting the driver to stay on the road is presented in relation to the identified situations and mechanisms.

Crash test methods for some typical run off road scenarios are suggested. Important occupant protection aspects concern mainly occupant retention as well as vertical loading through the seat. System test methods complement the whole vehicle tests, simulating the mechanisms behind these occupant protection aspects.

Run off road events are complex and require a broad approach, addressing the whole sequence of the event, and a large variation of situations. The proposed test methods will help address this topic. Special challenges apply to the simulation of the human, both in the avoidance methods and the crash testing. Addressing this area as a whole, technology developments are needed in a number of areas including sensor and trig algorithm developments, active safety technologies, restraint system design and tuning of seat and interior structure designs as well as post-crash technology.

CITATION: Jakobsson, L., Lindman, M., Axelsson, A., Lokensgard, B. et al., "Addressing Run Off Road Safety," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(1):2014, doi:10.4271/2014-01-0554.

INTRODUCTION

Run off road events are frequent and can result in severe consequences. In US, single vehicle roadway departure crashes accounted for about 20% of all police-reported crashes [1]. In Germany, 33% of all fatal crashes were run off road crashes [2]. In Sweden since 2003, single car crashes is the most common type when it comes to fatal accidents [3]. Injuries can be sustained to any body part. Among injury types highlighted as related to run off road events are thoracic and lumbar spine injuries. Although found in all crash situations, Jakobsson et al. [4] showed that AIS2+ thoracic and lumbar injuries were mostly found in multiple events; a high proportion of the cases being run-off road crashes. Occupant posture, such as forward bending was highlighted as an influencing factor, with the injury mechanism of spinal axial loading with different degree of flexion leading to compression and anterior wedge fractures, especially seen in run off road events with complex occupant kinematics.

The reasons for leaving the road are numerous, Najm et al. [5] analyzed police-reported crashes in NASS-GES; 37% of single vehicle off-roadway crashes involving light vehicles were preceded by a control loss event. In 15%, the driver tried to avoid another vehicle or object on the roadway before exiting and in 3% a vehicle component failure, such as blow out tire led to control loss. Analyzing fatal crashes in USA, Liu and Subramanian [6] identified driver related (eg. sleepiness, alcohol, speeding) as well as environmental factors (eg. adverse weather, roadway alignment with curve, rural roadway, high speed limit road) as significant factors related to the high risk of fatal single-vehicle run-off-road crashes. Studying pre-crash factors for fatal and non-fatal crashes in US NMVCCS data, driver performance errors (eg. overcompensation and poor directional control) were identified as the most critical reasons, followed by driver decision errors, critical non-performance errors and recognition errors [7]. Roy and Dissanayake [8] identified night time, weekends, adverse weather, rural area, gravel and paved roads, higher speed

limits, wet and icy road surface among the most common characteristics of run off road crashes. While, driver fell asleep, ill or medical condition, driving under the influence, too fast for conditions, tires and wheels, strong winds, freezing rain, shoulders, ruts, holes, and bumps were found to have a greater role in contributing to run off road crashes than on road crashes. Swedish fatal run off road crashes occurred mostly at weekends in evenings/nights and on roads with posted speed limits 70 and 90 km/h [3]. In the Swedish study, half of the fatally injured were unrestrained; the vast majority of the drivers (86%) were males and 38% below age 25. Additionally, half of the drivers were under influence of alcohol or drugs. Based on a literature review, Pompili et al. [9] indicated that more than 2% of the fatal single vehicle crashes were suicide behaviors.

Examples of countermeasures are vehicle technology such as Electronic Stability Control (ESC). Based on a literature review, the overwhelming majority of studies found ESC highly effective in reducing single vehicle crashes [10].

In the context of crash avoidance, numerous test methods and evaluation procedures address situations triggering potential run off road crashes, such as sleepiness [11, 12, 13] and distraction [14, 15, 16]. Additionally, test methods evaluating specific technology such as Electronic Stability Control (ESC) and Lane Departure Warning (LDW) are found within legal and public domain testing. However test methods addressing run-off road safety in a wider context are scarcer, although first steps are taken e.g. within the Advanced Crash Avoidance Technologies Program at NHTSA [17].

Leaving the road can result in a variety of more or less complex events. While, some vehicles quickly come to a rest position without any severe event, other vehicles leave the road into a free flying event, landing on the wheels or continues into a roll or turn-over event or interact multiple times with the environment. In-depth studies in Austria highlight the effect of guardrails leading the vehicle to "take off" as well as vehicles jumping into road side objects such as traffic sign poles or overpasses [18]. Being a complex event, not one single test method addresses this whole area of concern. Some parts of some events, such as skidding sideways and impacting a tree, are addressed in standardized lateral pole impact tests. Additionally, standardized frontal barrier tests address parts of events ending up into a large rock or a brick wall. However, neither influence of potential change in occupant posture before impact, nor reasons for leaving the road will be covered in these standardized crash tests.

Addressing run off road safety poses a variety of challenges, ranging from understanding the reasons for leaving the road to means of evaluating the potential injury outcome, all put into the overall context of run off road safety. Hence, the objective of this study is to identify different situations and mechanisms both in respect to crash avoidance and occupant protection and to present test methods addressing the different identified mechanisms for run off road occupant safety.

HOLISTIC METHODOLOGY ADDRESSING RUN OFF ROAD SAFETY

This study was based on a holistic perspective of safety, covering the whole event from normal driving to crash care as well as the dimensions of human, environment and vehicle, as illustrated in Figure 1. Three main areas were used to structure the study; Pre-crash parameters, Run off road situations and Occupant injury. The different areas address overlapping parts of the run off road event, as shown in Figure 1. **Pre-crash parameters** are human, environmental and vehicle states potentially influencing the occurrence of the run off road crash. **Run off situations** specify the conflict situation prior and just at running off the road as well as the sequence after. **Occupant injury** addresses the outcome of the run off road crash, focusing occupant injury in relation to type of injury-inducing impacts.

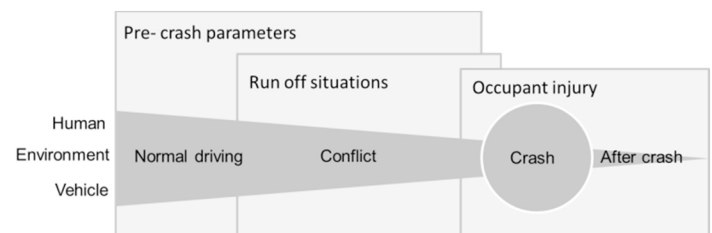


Figure 1. Holistic view of run off road safety

Real world data provided information on situations and influencing factors leading to understanding of mechanisms related to occurrence of the event as well as occupant injury (Figure 2). Based on these mechanisms, some test methods for evaluation of technology were suggested.

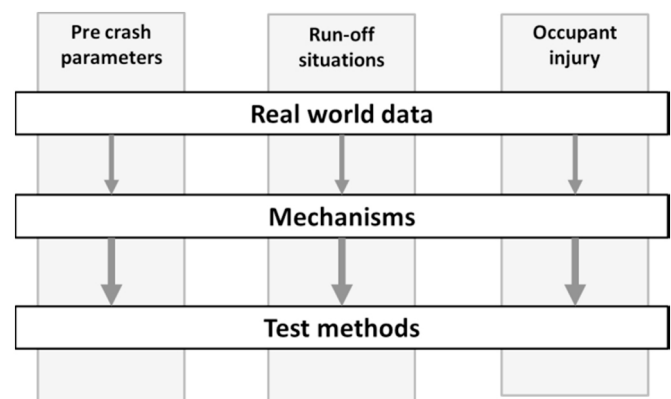


Figure 2. Structure of study set-up

REAL WORLD DATA

Aiming for understanding of crash causation mechanisms and injury causing mechanisms, situations and influencing factors were identified using real world data. Different types of information were combined; statistical and in-depth crash data from Volvo Cars' Traffic Accident Database and driving data from Volvo Cars' NDS/FOT Database.

Run off road crashes were defined as crashes where the car initially left the roadway. In the following sequence it collided with an object outside of the road area, came to a rest, overturned or re-entered the roadway thereby interacting with a road user or another obstacle on road.

Volvo Cars' Traffic Statistical Accident Database (VCTAD) contains data about Volvo passenger cars in Sweden. Detailed information about the database is found in [19].

Restrained drivers with known injury severity involved in crashes during 2002-2012 (car model years 1999-2012) were selected for the analysis. 1721 run off road crashes were compared to 4698 on-road crashes, i.e. without initial roadway departure. The overall injury risk was defined as the number of occupants injured for a certain level of AIS, divided by the total number of occupants (injured as well as uninjured) in the group considered. Exact 95% confidence intervals were calculated based on the Binomial distribution. For crash characteristics and pre-crash parameters, descriptive analysis and chi-square tests were used to assess the differences in percentages of the two groups of crashes. Additionally, occupant injuries in run-off-road crashes were investigated.

Volvo Cars regularly performs *in-depth crash investigations* of crashes of special interest. For these in-depth cases, on-site investigations are carried out and detailed information is collected and recorded. Three in-depth real world cases were selected in this study to illustrate and to provide further understanding of influencing factors.

Volvo Cars' NDS/FOT data base comprises data from 100 Volvo cars driven in real traffic during one year as a part of the EuroFOT project [20]. In total 195 car drivers are included in the database, which consists of 1.069.460 driven kilometers and 26.019 hours of data. Data was recorded continuously at 10Hz during the whole trips and included camera views (e.g., forward road view, rearward road view and driver view), onboard sensors, and CAN-bus signals. Objective information on run-off-road occasions was studied using 'true-positive' events; the rationale is that if there was not a system activation, the situation would likely result in a run off road crash. In this analysis, the Lane Departure Warning (LDW) plus large steering wheel jerk and unintentional steering away were used as triggers to identify critical lateral events. Furthermore the 'true-positive' events were manually annotated, by reviewing the video, into a well-defined set of coding variables described as conflict situations. 14 events were selected in this study and studied in terms of pre-crash parameters and for specifying the run-off-road situations.

Pre-Crash Parameters

VCTAD contains statistics concerning driver state and activity before and during the crash, on the surroundings and on vehicle equipment. Table 1 displays categorical environment,

driver and vehicle state parameters for with significant differences in percentages when associating run off road crashes to on-road crashes.

The statistics showed that 75% of run off road crashes occurred at rural roads including highways as compared to 58% of the on-road crashes (Table 1). Also, road departures took place more often in curves. Almost one third of the run off road crashes happened in darkness while 23% of the on-road crashes did so. 21% of the run off road crashes occurred during adverse weather conditions (rain or snow), which is almost relatively twice as many as in on-road crashes.

Information on driver fatigue and inattention was investigated for a subsample including accident years 2005-2011. Fatigue was reported in 12% and inattention in 33% of the run off road cases, as compared to 4% and 22%, respectively, of the on-road crashes (Table 1). Young drivers aged 18 to 25 years, were overrepresented in run off road crashes.

As can be seen in Table 1, a major part (55%) of the run off road crashes was preceded by a loss of control event, this is almost a five times higher percentage of skidding than in on-road crashes. 71% of the drivers reported a higher speed than 40 km/h in run off road crashes. This can be compared to slightly more than 40% in on-road crashes. In Sweden, winter and summer seasons can appear very different in terms of road status. Use of winter tires is prescribed during winter season when the roads are snowy or icy. In 51% of run off road crashes and 40% of on-road crashes, ordinary tires were used in situations when the roadway was covered with snow/ice.

Table 1. Percentage of pre-crash parameters in run off road- and on-road crashes, respectively, together with p-values for Pearson chi-square statistics of association.

precrash factor	run-off-road crashes (%)	on-road crashes (%)	P-value
driver fatigue	11.63	3.59	<.0001
driver inattention	32.68	21.78	<.0001
rural road or highway	74.97	58.4	<.0001
curve	43.43	14.67	<.0001
darkness	30.26	23.09	<.0001
rain or snow	21.08	11.75	<.0001
drivers age <26 years	14.47	6.92	<.0001
summer tires on road with snow/ice	50.94	40.21	0.0058
skidding	54.58	11.31	<.0001
speed at impact >40 km/h	71.27	42.64	<.0001

In-depth crash data adds insight into the pre-crash events and provides examples of pre-crash parameters as well as offers comprehension into the complexity of influencing factors.

In in-depth crash data **Case I1**, an un-experienced male driver aged 20 years old, taking driving lessons, drove a Volvo V70 along a rural road in 60-70 km/h during daytime. It was raining and the road was wet. He was a bit stressed as he had an appointment to keep. In a slight left bend of the road, an oncoming vehicle approached in high speed close to the centerline. The driver of the Volvo reacted keeping too far right, and the car departed the road way as illustrated in Figure 3.

The cause was probably a combination of insufficient skill/knowledge due to inadequate training and insufficient experience of the road and stress due to time pressure, leading to misjudgment of the distance to the other vehicle and the sharpness of the curve.



Figure 3. Schematics of event, in-depth crash data Case I1

In in-depth crash data **Case I2**, an experienced male driver aged 70 years old was driving his Volvo S60 in the middle of the day. He was on his way home from the golf course (a trip of 15-20 minutes). He was very familiar with this route and he was late for lunch. After 10 minutes driving, the car ran off the road to the right on a rural road with speed limit of 70 km/h in a slight left bend and slight slope (Figure 4). The road was dry and somewhat rutted asphalt, 8 meters wide with low traffic intensity. The weather was sunny with a potential for direct sunlight into the driver's eyes. The exact cause cannot be determined, but several possibilities exist such as; blackout, couldn't see due to sunlight or was not capable of handling the speed.



Figure 4. Schematics of event, in-depth crash data Case I2

In in-depth crash data **Case I3** a male driver aged 40 was driving his Volvo S80 on a rural road with speed limit of 90km/h. It was daytime, the road was partially slippery due to ice. When he had driven 15 minutes of the in total 1.5 hour long trip, suddenly a deer appeared on the road. He tried to steer and lost control of the car and ran off the road to the right. It is unclear whether he applied the brakes, neither could he judge how much influence the slippery road had on his road departure. The cause of this run off road crash was a sudden appearance of the deer and the driver's reactions based on this, also potentially contributing was the lack of road grip.

Analyzing driving data of 14 selected cases, all being 'true-positive' Lane Departure Warning (LDW) situations; different pre-crash parameters could be identified. In all the 14 events the vehicle speed was between 60 and 100 km/h. Eight of them were on rural roads (one case on 90km/h limit and seven cases on 70 km/h posted speed limit), four events on the motorway with 90km/h or 110km/h posted speed limits and two in the city with 70km/h posted speed limit. With respect to environmental states, all but one case occurred in daylight. In one case it was raining and in 2 other cases there was snow on the sides of the road, but not on the road. Driver state parameters influencing the events were mainly distraction and tiredness. Typical distraction was texting (4 cases), dialing and talking on a cell phone (1 case), eating (1 case) and/or external distraction in the environment (3 cases), internal distraction, i.e. looking for something (3 cases) and talking to passengers (2 cases). Four cases will be presented more in detail to provide more insight.

In the driving data **Case D1**, a family of four was traveling in an unfamiliar area on their way to a ski vacation in Norway with their Volvo V70. The father, aged 41, was driving the car on a rural road with 70km/h speed limit and oncoming traffic. He was driving with longitudinal speed 70km/h and lateral speed 1 km/h. The weather was sunny. The driver was looking around at the surroundings while talking to the front seat passenger and didn't take notice when the vehicle exited from the lane markings on the right side. The heading angle was 2.8 degrees relative to the road markings. After the received lane departure warning (LDW), the driver quickly steered back into the lane.

In the driving data **Case D2**, a male aged 57 was driving a Volvo V70 in 80km/h on a rural road with oncoming traffic. The posted speed limit was just changing from 90km/h to 70km/h. It was daylight and the weather was clear. The driver was on his way home from work, hence familiar with the road. He was texting on a cell phone, while continuously shifting the gaze between the cell phone and the road ahead. The vehicle started drifting out of the lane to the right side and the LDW was issued. The lateral speed was 1.6 km/h and the heading angle 1.1 degrees. After hearing the warning the driver steered back into the lane, and continued with the texting.

In the driving data **Case D3**, a father of age 46 and two children were traveling home in a Volvo XC70 after spending the day in the countryside. It was daylight and rainy weather, the driver was driving in 70km/h on a rural road. After 5 min of the trip, the driver was holding the steering wheel with one hand and using the other to unpack a food package. He was constantly shifting his gaze towards the road ahead and down on his lap. While looking down, the vehicle started drifting to the right, with a lateral speed of 3 km/h and a heading angle of 8.6 degrees. The driver finished with the distracting task and continued driving with the both hands on the steering wheel.

In the driving data **Case D4**, the male driver of about 20 years old was driving alone in a Volvo XC70 around midnight in clear weather. The driver drove on a highway 2+1 lanes with 100