Predicted road traffic fatalities in Germany: the potential and limitations of vehicle safety technologies from passive safety to highly automated driving

Nils Lubbe, Hanna Jeppsson, Arian Ranjbar, Jonas Fredriksson, Jonas Bärgman, Martin Östling

Abstract It has been proposed that automated vehicles will greatly increase road traffic safety. However, few attempts have been made to quantify this thesis and to compare the expected benefits with more traditional safety systems. This study was carried out in five steps, adding systems in each step (from passive safety, standard Advances Driver Assistance Systems (ADAS), advanced ADAS, safety-minded driving, to cautious driving) in order to capture the benefit of increasing levels of automation. Conservative and optimistic rules based on the expected performance of each safety system were developed and applied to the German In-Depth Accident Study database. Adding safety systems was effective in preventing fatalities, ranging from 12–13% (step 1, passive safety, no automation, conservative-optimistic estimate) to 45–63% (step 5, cautious driving). The highest automation level, in step 5, achieved a reduction of Vulnerable Road User (VRU) fatalities of 33–41%. Thus, passive and active safety systems contribute substantially to preventing fatalities and their further development and deployment should not be abandoned. Even the safest foreseeable, highly automated passenger cars are not likely to avoid all crashes and all road traffic fatalities. While increased market penetration across safety systems will make road traffic substantially safer, more efforts are needed to protect VRUs.

Keywords Automated driving, Integrated safety, Benefit, Forecast, Residual problem.

I. INTRODUCTION

Comprehensive literature reviews have shown that advanced safety systems and automated driving are expected to improve road traffic safety [1-2]. However, only a few attempts have been made to quantify this expectation and to compare the expected benefits. Benefit estimates for single Advanced Driver Assistance Systems (ADAS) are widely available, but as [3] states, ‘until now, there has been no empirical proof of the overall safety gains of fully automated driving functions’. In [4], future injury crashes at higher levels of automation were predicted by means of expert judgments. Crashes caused by passenger cars were estimated to be non-existent by 2070. Until then, [4] estimated that the crash types Turning and Crossing will be relatively more frequent compared to today’s crash scenarios. No consideration was given to crashes not caused by passenger cars or to different levels of injury severity.

References [5-6] can serve as examples for single ADAS benefit estimates. Both estimate the benefits of implementing a range of ADAS, based on simple assumptions about which types of crash they address, as recorded in insurance claim data [5] and the in-depth German In-Depth Accident Study database (GIDAS) [6]. While these studies are appealing as they produce consistent estimates for a wide range of technologies, they do not sufficiently consider limitations of the technology, such as operation in inclement weather or high driving speeds. More importantly, the estimates for single technologies do not allow for an estimation of the safety benefits when bundles of technologies are introduced. Different technologies can address the same crash type to a large extent. Introducing multiple technologies will not simply lead to a summation of safety benefits, the so-called problem of double counting. In the extreme case of technologies addressing identical crashes, no additional benefit derives from their introduction. The problem of ‘double counting’ has been acknowledged and addressed by empirical correction factors [7] or, more recently, by applying a deterministic effect calculation on a case-by-case basis, which recognises and accounts for a single case being addressed by multiple technologies [8]. The deterministic ‘residual problem analysis method’ [8-9], using simplified rules for a range of technologies, can be implemented to estimate effects of combinations of safety technologies. It has been applied to predict the future

Dr N. Lübbe (e-mail: nils.lubbe@autoliv.com; tel: +46-322626940), H. Jeppsson and M. Östling work at Autoliv Research. A. Ranjbar is a PhD student and Dr J. Fredriksson is a Professor, both at the Department of Electrical Engineering at Chalmers University of Technology. J. Bärgman is Associate Professor at the Mechanics and Maritime Department at Chalmers University of Technology.

of Swedish road traffic fatalities [8][10], and to forecast the effect of passive and active safety deployment on road traffic fatalities in India [11] and the USA [12].

We aim to estimate the road traffic fatality prevention from passive safety to highly automated driving using the approach of simple deterministic rules for a range of technologies. All calculations include a conservative estimate and an optimistic estimate. Furthermore, we aim to provide an analysis of effectiveness by road-user type and describe remaining crashes to guide further development of future technologies.

II. METHODS

GIDAS provides detailed information about all kinds of traffic accidents in Germany. About 2,000 traffic accidents involving at least one injured person are recorded annually in the areas around Hannover and Dresden by special investigation teams. Detailed information about each participant, such as vehicle dimensions, deformation and safety systems are measured and photographed on the accident scene. The environment around the accident is also documented, road type and condition, obstructions and weather are typical variables that are recorded. All gathered information is stored in the database and the accidents are later reconstructed with information regarding the participants velocity, acceleration etc. While oversampling severe injuries [13], GIDAS is seen by some authors as directly representative for crashes with personal damage in Germany (e.g. [6]). Others argue that German representativeness is reached after results are weighted to German national statistics for injury severity [14], or several variables [15-17]. As our study addresses only fatalities, weighting for injury severity was not necessary, therefore unweighted data was used.

GIDAS data from 1999 to 2016 (completed cases in GIDAS release June 2017) yielded 810 road traffic fatalities in 747 crashes for analysis, of which 568 occurred in 519 crashes involving at least one passenger car (ECE regulation vehicle type M1 [18]). The fatalities are distributed across road-user types as follows: 50% car occupants; 21% pedestrians; 15% motorcyclists; 9% cyclists; and 5% others and unknown.

We studied the effects of passive safety systems and ADAS that are considered for EU regulations [2], as well as the more conceptual 'safety-minded driving' and 'cautious driving', as listed in Table I. Simple rulesets were created for each system and verified (see Appendix A for the conservative rules and Appendix B for the optimistic rules). Verification included checking sensitivity of the rules, reviewing a few randomly selected cases in-depth and comparing resulting effectiveness of single technologies to previous literature (Table II). All rules included one optimistic and one conservative estimate of system effect to account for the uncertainty stemming from differences in systems on the market and simplifications in their descriptions. For both estimates, optimistic and conservative, ADAS were modelled to operate only in specific speed ranges: input came from Euro NCAP assessment procedures and test results as well as from function description in driver manuals [19-21] and on webpages [22-23]. For the conservative estimate, performance limitations stem from to poor road conditions, including snow and ice on the road, as well as missing lane markings, reduced sensor visibility from precipitation, and unstable vehicle dynamics from skidding and speeding. All analyses assume 100% implementation of the evaluated systems in the passenger cars. However, for rules based on accident type, only the relevant vehicle (for example for AEB rear-end, only the striking vehicle in a rear-end collision scenario) was assumed to be equipped.

Based on these rulesets, systems were bundled in five steps, consecutively adding more and more safety systems. In each higher step, the previous step systems were considered present. Step 1: passive safety only. Step 2: standard ADAS including AEB (all types), ISA, LCA, LKA, and ESC. Step 3: advanced ADAS, adding V2X functionality to AEB V2X crossing, AEB pedestrian and AEB cyclist. Step 4: safety-minded driving. Step 5: cautious driving. The original sample (N = 810) is referred to as Step 0.

The rules were then applied to the dataset, checking that each case was addressed by at least one of the rulesets and, if so, the case was marked as prevented (A flowchart can be found in Appendix C). For passive safety systems, we investigated the most severe collision in a crash and then examined fatalities on an occupant level: a driver airbag may prevent a driver fatality, but does not necessarily prevent all fatalities in a crash. For active safety technologies, we investigated the first collision of a crash and assumed that preventing that first collision would mean preventing the crash (with all its potential collisions), and hence all fatalities that occurred in the crash. This deterministic approach avoided problems with double counting of safety benefits because even if several technologies could potentially prevent one fatality, the prevention was counted only once and thus fatality prevention of a bundle of dependent technologies was determined.

TABLE I
DESCRIPTION OF SAFETY SYSTEMS

Safety system	Description	Typical crashes addressed
Seat-belt reminder	Reminds all occupants to put on seat belts	Un-belted crashes
Frontal airbag	Driver and passenger airbag for frontal impacts	Frontal crashes without airbags
Side airbag	Side and curtain airbags	Side crashes without airbags
Improved airbag	High-performance frontal airbag	Frontal crashes with “standard” airbags
AEB rear-end	Detects vehicles driving ahead. The driver is warned and if not reacting, braking will be activated.	Impact to rear end of vehicle in same line
AEB back over	Detects the presence of vehicles behind and automatically initiates braking or prevents acceleration	Impact to another vehicle when reversing
AEB pedestrian	Detects pedestrians ahead. The driver is warned and if not reacting, braking will be activated.	Crossing and longitudinal pedestrian accidents
AEB cyclist	Detects cyclists ahead. The driver is warned and if not reacting, braking will be activated.	Crossing and longitudinal cyclist accidents
AEB animal	Detects animals ahead. The driver is warned and if not reacting, braking will be activated.	Crossing and longitudinal animal accidents
AEB pedestrian reversing	Detects pedestrian behind the car. Automatic brake applied when an impact is likely to occur.	Reversing accidents with pedestrians
AEB intersection	Detects crossing vehicles at an intersection. The driver is warned and if not reacting, braking will be activated.	Crossing and turning in intersections
Intelligent speed adaptation (ISA)	Detects that the vehicle speed does not exceed a safe or legally enforced speed.	Speeding
Lane Change Assist (LCA)	Detects when a car has entered the blind spot or a fast approaching vehicle enters the blind spot while the driver is switching lanes. The driver is warned by visual and acoustic signals.	Side swipe and rear-end collision when changing lanes
Lane Keep Assist (LKA)	Detects that the vehicle is about to drift beyond the edge of the road or into oncoming or overtaking traffic in the adjacent lane and automatic steer back.	Run off road, drift into oncoming vehicle, side swipe
Electronic Stability Control (ESC)	Detects loss of steering control and automatically applies the brakes to help "steer" the vehicle where the driver intends to go.	Skidding
AEB V2X functions	V2X is communication between road users, allowing to see through obstacles.	All scenarios
Safety-minded driving	No violation of any traffic rules.	All scenarios
Cautious driving	Adapt driving to conditions, e.g. visibility and weather.	All scenarios

Analyses

The analyses first show the share of fatalities prevented (out of a total of 810) by the stepwise increase of safety system implementation, from passive safety only to highly automated driving, which is represented as cautious driving. Secondly, crashes where fatalities occur (N=747) were analysed to show how collision partners and impact types change in the remaining crashes. Here, impact types are defined as front-front, front-side, front-rear and other collisions, based on the general area of damage of the involved vehicles. Thirdly, crashes where fatalities occurred in passenger cars (N=519) were analysed for changes of accident scenarios and impact types in the remaining crashes. Accident scenarios are defined by the pre-crash motion in the first conflict (Appendix D), adapted from [24]. Fourthly, the crash situation for fatalities in passenger cars (386 fatalities in 345 vehicles) was characterised by the Principal Direction of Force (PDOF), which characterises the impact direction and delta v, which in turn gives the change of velocity due to the impact for the remaining accidents in each step of increased safety system implementation.

III. RESULTS

Validation of safety rules

For validation of the rules, we calculated conservative and optimistic estimates for effectiveness of individual technologies and compared it with estimates from literature, as shown in Table II. (Note that both estimates yielded the same value if only one value is given.) For passive safety systems, our estimates generally indicate lower fatality reductions compared to estimates from the USA, and hence are conservative. For ADAS, if point estimates are given in previous literature, our estimates are again slightly lower. With the exception of ISA, when an effectiveness range was given in previous literature, our range overlaps at least to some degree. For ISA, we estimate a much lower potential to save lives compared to previous literature.

TABLE II
PASSIVE SAFETY AND ADAS FATALITY PREVENTION EFFECTIVENESS

Technology	Literature finding	Our estimate
Seat-belt reminder: 3-point belts for unbelted occupants	45% fatality reduction front-seat occupants in passenger cars in all types of crash [25]	25.6–29.3%
Frontal airbags: Driver Frontal Airbags for unequipped vehicles	12% fatality reduction for drivers in all types of crash [25]	7.0–7.4%
Side airbags: Driver Head and Torso Airbags for unequipped vehicles	37–52% fatality reduction for drivers in driver-side crashes [26]	31%
AEB rear-end	1.8–2.2% fatality reduction in all types of crashes involving at least one passenger car [5]	2.5–2.6%
AEB back over	0% fatality reduction in all types of crash [27–28]	0.2%
AEB pedestrian	3–82% fatality reduction in crashes with car front-end [29]	53%
	1.6–40.4% fatality reduction in crashes involving at least one passenger car [5]	1.4–7.7%
AEB cyclist	6–84% fatality reduction in crashes with passenger car front-end [29]	22.2%
AEB intersection	2.7–8.3% fatality reduction in crashes with passenger cars ([30] and [31]*)	0.9%
ISA	37–59% fatality reduction in all types of crashes [32]	0.5–2.1%
LCA	1.1–2.1% fatality reduction in all types of crashes involving at least one passenger car [5] 1% fatality reduction in all fatal crashes [33]	0.4–1.2%
LKA	5.5–14.7% fatality reduction in crashes involving at least one passenger car [5], 16% [34] fatality reduction in all crashes	3.9–16.7%
ESC	8.8–34.4% fatality reduction in crashes involving at least one passenger car, rear-end excluded [35]	7.4–29.7%

* calculated from AEB effectiveness in collision avoidance in LTAP/OD and SCP scenarios, weighted to LTAP/OD and SCP scenario share in fatal crashes. This estimate is likely lower than the true effect of AEB in all fatal intersection crashes.

Effectiveness of increased automation in preventing road traffic fatalities

Increasing automation prevents more and more road traffic fatalities (Fig. 1). Notably, already standard ADAS (Step 2) is estimated in this study to reduce road traffic fatalities by 27–45%; with the highest level of automation (Step 5), this increases to 45–63% (Fig. 1, left). The effectiveness in preventing road traffic fatalities is a combination of large numbers of prevented passenger car occupant fatalities (Fig. 1, middle) and lower numbers of prevented Vulnerable Road User (VRU, includes pedestrians, cyclists and motorcyclists) fatalities (Fig. 1, right). All numbers can be found in Appendix E. Note that as the automated systems are bundled in this analysis, direct comparisons with literature on individual systems (Table II) is not possible.

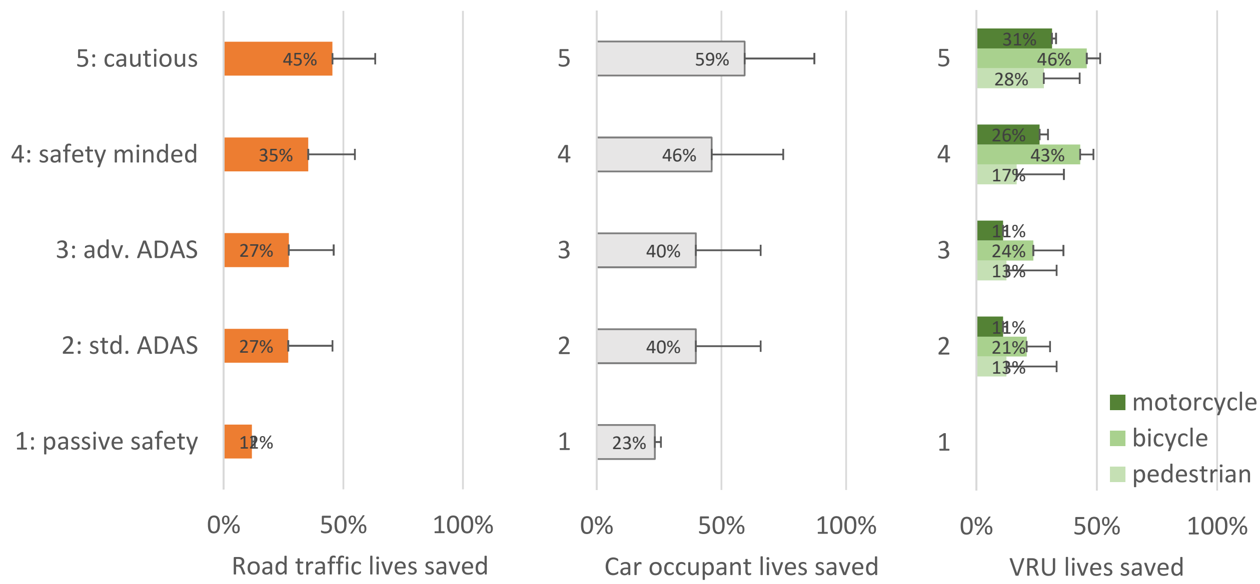

Fig. 1. Fatalities prevented by the five steps of automation. Left: all road traffic fatalities. Middle: Passenger car occupants. Right: Vulnerable Road Users. Bar and values depicted are the conservative estimate, error bars (T-bar lines) depict the optimistic estimate.

Analysis of the remaining crashes

This study shows a shift in the type of collision partner in fatal road traffic crashes. In Step 0, accidents not involving passenger cars and passenger cars colliding with object or run off road accounted for 60% of fatal crashes (Fig. 2, top). In step 5, cautious driving, accidents not involving passenger cars alone accounted for 66% (Fig. 2, bottom). Frontal crashes remain dominant in terms of fatal crashes. Figures for all five steps, with conservative and optimistic estimates, are given in Appendix F. Intermediate steps generally follow the overall trend of increasing number of non-passenger car crashes and crash partners, while in the conservative estimate object off-road remains more frequent than in the optimistic estimate.

Figure 3 describes the situation for fatal crashes involving passenger cars and show a shift in the top 10 accident scenarios. In Step 0, vehicle and driver loss of control represents almost 40% of all crashes (Fig. 3, top). After introducing Step 5, cautious driving, VRU crossings account for 15% of the remaining fatal accidents (Fig. 3, bottom). Figures for all steps, with conservative and optimistic estimates, are given in Appendix G. Conservative estimates indicate higher relevance of loss-of-control crashes compared to optimistic estimates, but both estimates indicate increased relevance of VRU accidents with increasing levels of safety system implementation.

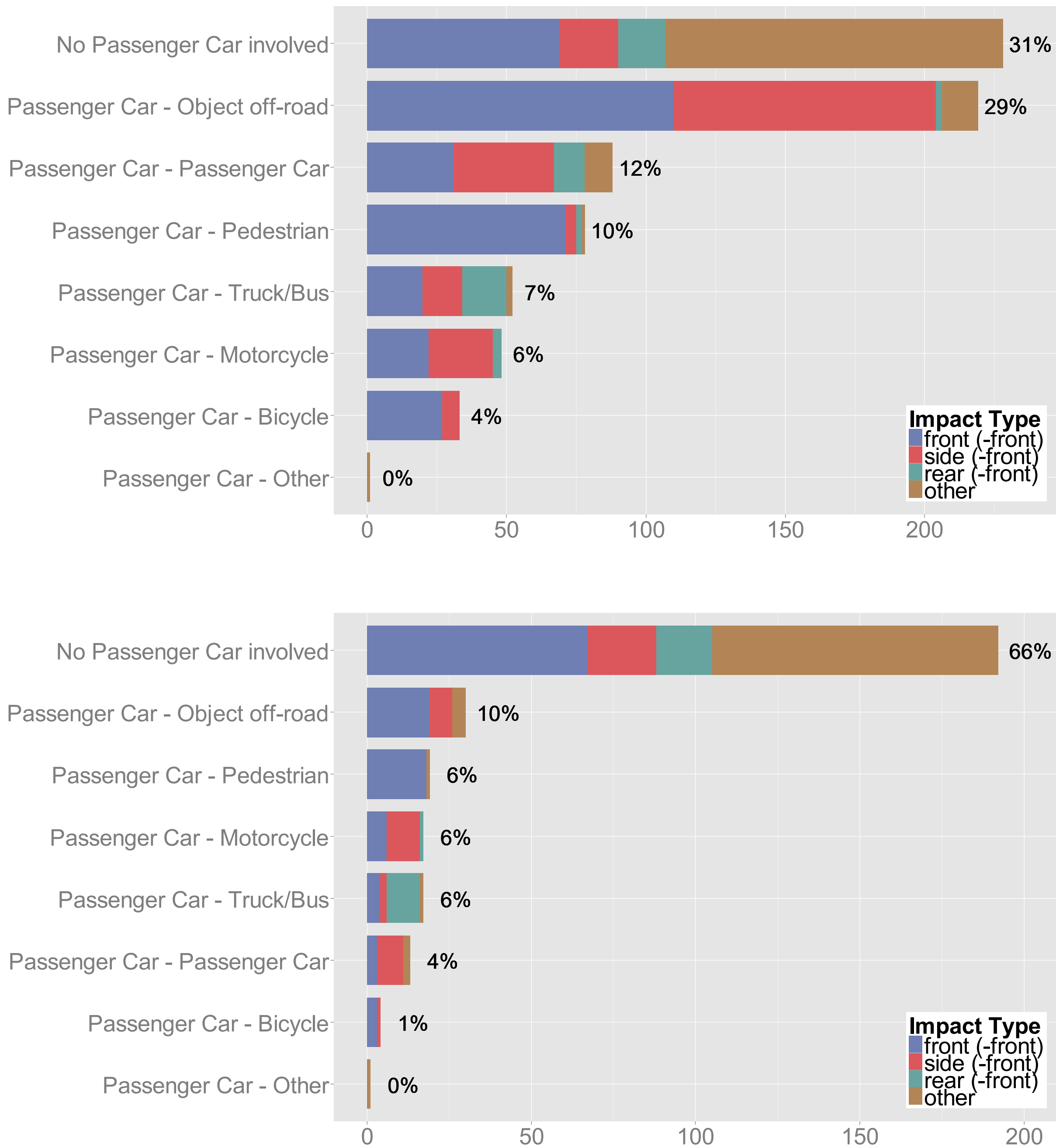

Fig. 2. Collision partner in fatal road traffic crashes. Top: Step 0 (N=747). Bottom: Optimistic residual population after step 5, cautious driving, N=293.

Finally, Fig. 4 shows how the crash situation changes for fatalities in passenger cars. Remaining crashes with higher levels of automation will occur at approximately the same impact direction (Fig. 4, left) as today's crashes, and at a slightly lower impact severity (Fig. 4, right). Appendix H gives the results for the intermediate steps. Frontal impact directions dominate all steps, in both conservative and optimistic estimates.

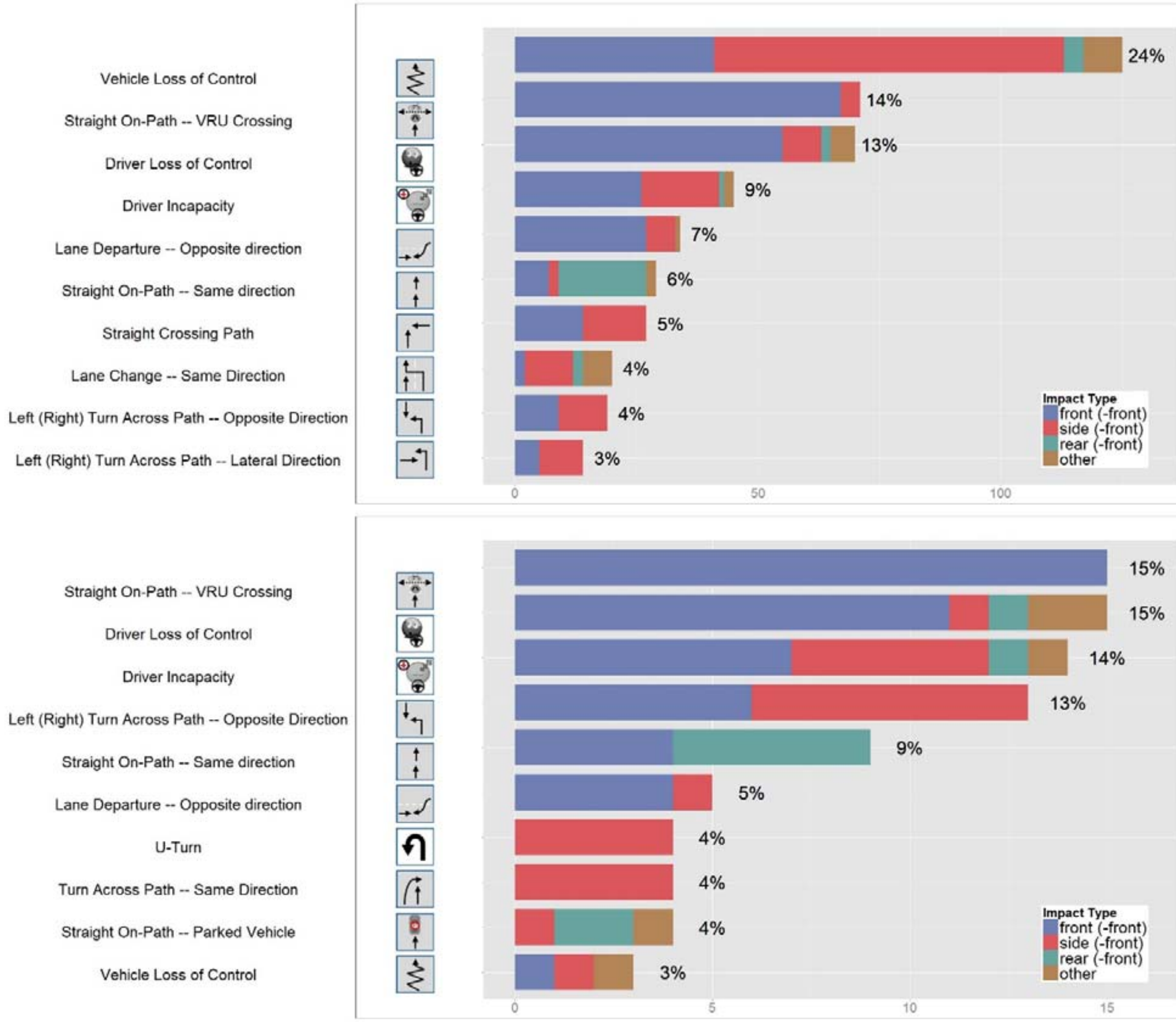

Fig. 3. Top 10 accident scenarios for fatal road traffic crashes involving passenger cars. Top: Step 0 (N=519). Bottom: Optimistic residual population after step 5, cautious driving, N=101.

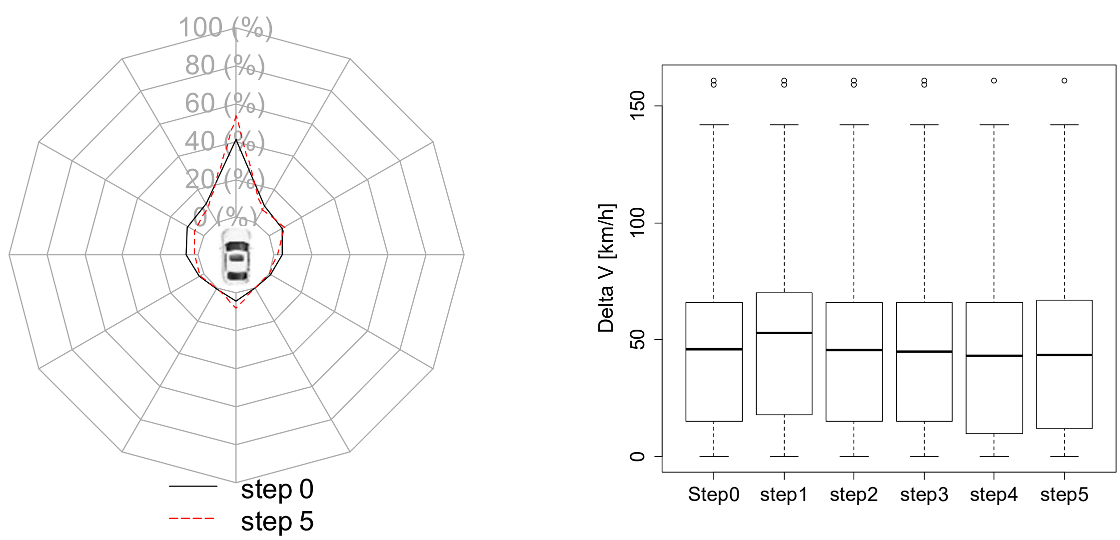

Fig. 4. Crash situations for passenger cars with increasing automation. Left: Crash direction (PDOF) for step 0 (N=343 vehicles with known PDOF) and optimistic step 5, cautious driving. Right: Crash severity (delta v) for all steps (optimistic estimate).

IV. Discussion

More safety systems equal more lives saved, and with the conceptual *cautious driving* up to 63% of fatalities can be prevented. Passive safety systems are estimated to prevent 23–26% of car occupant fatalities, indicating that there is still potential to further improve passive safety systems and ensure their use. As these systems were modelled to only protect occupants, other road users do not benefit. Given the high number of car occupant fatalities in Germany and GIDAS, these improvements for passenger car occupants will still substantially reduce the number of road traffic fatalities, by 12–13%.

V2X technologies were added as Step 3, removing system limitations due to visual obstructions, which did not lead to higher fatality reductions. This does not necessarily reflect the true potential, for a number of reasons. First, we only applied V2X functionality to a limited set of well-defined AEB functions; applications in the field may be wider. Secondly, GIDAS captures only permanent visual obstructions, for example by buildings. Temporary visual obstructions by other traffic participants cannot be captured, even though they are likely. V2X may provide benefit for temporary visual obstructions that were not captured in this study.

Aside from V2X as Step 3, the safety system steps increase by approximately 10% in each step. This indicates that each new step addresses fatalities not yet prevented in previous steps, and therefore appears to introduce relevant new functionality to a similar extent. Safety benefits are not restricted to, and not even disproportionally high on, the last step to highest automation – cautious driving. Development and deployment of safety systems below this step are relevant and give substantial returns.

Our effectiveness estimates highlight that car occupants will benefit more than other road users. In particular, pedestrian fatalities remain a challenge, with an estimated reduction of only 28–43%, even for the highest level of automation. These findings are in line with [11], where an even higher difference in possible fatality reduction between car occupants and other road users was reported for India. One explanation for the lower effectiveness for VRU protection in this study could be that VRUs behave erratically and that the safety systems cannot handle these situations. Another reason could be that these accidents are not well documented, with many unknowns, hence making it difficult to appropriately apply deterministic rules. We have not modelled advanced passive safety systems for VRU protection, such as hood lifters and VRU-protection airbags, which are effective in reducing VRU fatalities, [36-38], but are deemed too complicated to be represented by simple rules.

Manufacturers should consider equipping not only passenger cars but all vehicles with advanced safety systems. We simulated equipping all road vehicles (cars, buses, trucks, motorcycles) and found that 57–82% of road traffic fatalities could be avoided in Step 5, compared to 45–63% when equipping passenger cars only (for details, see Appendix E). The obvious limitation of improving passenger car safety is that not all road traffic crashes involve passenger cars, therefore protective systems need to be developed and applied to other road users as well.

It comes as no surprise to discover that analysis of the residual shows an increasing number of 'no passenger car involved' crashes with increasing automation. This trend was more pronounced for the optimistic estimates, but it is found in both the optimistic and conservative estimates.

Accident scenarios show some interesting patterns. First, one should recall the concept of *automated driving* as c*autious driving,* by which accident causations are excluded that are deemed a consequence of non-adapted or irresponsible driving (see Appendix A and B). Accident scenario classification is based on accident types. We refer to accident types involving single vehicles with no, or unknown, skidding prior to crash as *driver loss of control* (Appendix D). While it may be hard to understand how driver loss of control can be a problem for automated cars, it appears reasonable that single vehicle accidents with no or unknown skidding prior to crash may still occur. Most remaining *driver loss of control* have unknown accident cause or the unspecific accident cause: '*49: Other mistakes made by driver*'. Hence, the remaining *driver loss of control* crashes may be largely attributed to data and coding issues rather than representing a specific and well-defined problem in future crashes. While we choose to keep this nomenclature and categorisation for the sake of consistency with other publications, these accident scenarios may cause some confusion. It is therefore important to refer to their definitions and keep in mind that a substantial amount of unknown and unspecific cases end up in these categories.

A more straightforward observation concerns intersection crashes. Straight crossing path crashes are frequent until Step 4. It appears that ADAS is not very effective in preventing these crashes, likely due to our assumption of functionality at low speeds (up to 60 km/h) only. Safety-minded driving, on the other hand, which has no operational speed restrictions, is very effective. Given that most straight crossing path accidents are preceded by violation of traffic lights or right-of-way, this seems reasonable. In contrast, the other frequent type of intersection crash, left turn across path/opposite direction, remains prevalent throughout all steps, indicating that these crashes are usually not preceded by traffic rule violations. Again, these patterns can be seen in both the optimistic and conservative estimates.

It should be noted that ADAS has the potential not only to reduce fatalities but accidents of all severities, similarly to passive safety systems having the potential to reduce injuries of all severities. Therefore, it is of importance to use prospective analysis like this to predict future accident scenarios also at lower severities. This is needed, not only to guide the development of new or improved ADAS functionalities, but also to guide the development of new passive safety systems. The remaining accident scenarios and crash configurations (delta V and PDOF) should be the basis for strategies to develop new passive safety systems or ADAS to address not only fatal, but also injuries of lower severity.

Strengths and limitations

In this study we have used GIDAS – one of the most detailed and accurate crash databases in the world – as a basis for estimation of safety impact, in terms of fatality reductions, for a range of safety functions with increasing level of automation. Rulesets were applied to available GIDAS variables for each of the five levels of safety functionality addressed. By using an incremental and deterministic ruleset-based approach, we have been able to avoid double counting of crash avoidance, similar to the method used in, for example, [8-9]. Although the rulesets are relatively simple combinations of GIDAS variable filtering, providing one conservative and one optimistic benefit estimate, they do provide good insight into the potential of the systems. The approach of using a conservative and an optimistic estimate also alleviates the effect of inaccuracies and potential issues with precision of some GIDAS variables on benefit estimates, as a range of benefits is provided. The main drawback with this method is that fatalities caused by new systems are not addressed. That is, we only remove crashes from the available (mostly conventional) vehicle fleet. Any new crashes that are, even in part, due to new system implementations are disregarded. To enable inclusion of such new crashes in the estimates, very detailed simulations and in-depth understanding of the interplay between the driver, the vehicle (automation) and other road-users is necessary. Such virtual assessment methods are in focus across academia and industry [39-40], but more research is clearly needed. Similarly, interaction between active and passive safety systems were not modeled. Active safety was assumed to either prevent a collision or not to affect it. This simplification could again be avoided using more detailed virtual simulation of the systems.

Any shift in transportation modalities or urbanisation is not covered. If more drivers started riding bicycles instead of driving cars, there may, at least temporarily, be an increase in bicycle fatalities. Such fatalities are not considered in this prospective analysis of safety benefit using a retrospective crash population. With respect to market penetration, the analysis assumes full market penetration of the evaluated systems, therefore these are long-term estimates. Other methods would have to be employed to address partial market penetration [41]. With respect to the estimate of the safety effect of passive safety systems, we only considered protection by the airbag for the most severe collision in a multi-collision crash. This may result in slight errors in the safety benefit of passive systems (not obvious if resulting in over- or under-estimates). However, as the proportion of multi-collision crashes with (at least) two high severity collisions is likely to be low (24% of crashes in GIDAS are multiple-collision crashes [42]), and only a fraction of those would include two or more severe injury or fatal collisions, and airbags are usually inflated over longer times, this should provide protection even in subsequent collisions. We assume that airbag protection in the most severe collisions should be an appropriate compromise. It should also be noted that we did not model a specific airbag design (or a specific design for any of the safety systems) but the generic system airbag, assuming that the specific airbag design would be matching the specific vehicle where it is placed into. We believe that it is possible to design an appropriate airbag for each of the vehicles to obtain the injury reduction modelled. Finally, although there are limitations with the method used, the range of benefits provided with the conservative and optimistic rulesets does provide indications for the future of traffic safety and traffic safety systems, and can be used to highlight focus areas for future research and innovation.

V. CONCLUSIONS

Our estimates show that there will be road traffic fatalities in the future, albeit substantially less than occur today, even for the optimistic formulation of a conceptual model of *cautious driving*. Accordingly, we do not expect that automated driving will be fatality-free or even crash-free. While the benefits that seem achievable with vehicle automation are impressive, we need to continue efforts to bring more and better active and passive safety technologies into cars to address the residual problems. Future fatal crashes will likely involve less passenger cars. When passenger cars are involved, colliding with a VRU and losing control will be the predominant accident scenarios. Remaining fatal passenger car crashes are mainly of frontal impact direction and of a crash severity similar to today's crashes. Future studies should model the effect of even more safety systems for vehicles, improvements of infrastructure and road-user education, as they have not been addressed in this study.

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VIII. APPENDICES

APPENDIX A: PASSIVE SAFETY AND ADAS TECHNOLOGIES FATALITY PREVENTION CONSERVATIVE RULESETS

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APPENDIX A:
Passive safety and ADAS technologies fatality prevention conservative rulesets

<table>
<tr><th>Technology</th><th>Ruleset using GIDAS variables</th><th>Ruleset in text</th></tr>
<tr><td>Seat-belt reminder</td><td>klassece == 1
rhsben == 2
vdi6 <= 3 & vdi6 >= 0</td><td>M1 vehicle &
Belt not used &
non-catastrophic vehicle damage</td></tr>
<tr><td>Frontal airbags</td><td>klassece == 1
vdi2 == 1
airbf == 0
sreihe == 1 & (squer == 1 | squer == 9)
ais98reg1 == [1:6] | ais98reg2 == [1:6]
(vdi6 <= 3 & vdi6 >= 0)</td><td>M1 vehicle &
Frontal impact &
airbag not present &
first-row occupant &
injury to head present &
non-catastrophic vehicle damage</td></tr>
<tr><td>Side airbags</td><td>klassece == 1
vdi2 == [2,4]
airbdi == 0 | airbsi == 0 | airbti == 0
squer == 1 | squer == 9
vdi6 <= 3 & vdi6 >= 0</td><td>M1 vehicle &
Side impact &
no side airbag present &
occupant seated in outer position &
non-catastrophic vehicle damage</td></tr>
<tr><td>Improved airbags</td><td>klassece == 1
airbf == [1,2]
sreihe == 1 & (squer == 1 | squer == 9)
ais98reg1 == [1:6] | ais98reg2 == [1:6]
vdi6 <= 3 & vdi6 >= 0</td><td>M1 vehicle &
Frontal airbag present &
first-row occupant &
injury to head present &
non-catastrophic vehicle damage</td></tr>
<tr><td>AEB rear-end</td><td>klassece == 1
artteil <= 4 | artteil == 7
v0-v0_opp <= 70
strob ~= [6,7]
strzb ~= 4
schleu == 2
nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])
utyp == [201, 231, 541, 542, 549, 583, 584, 601, 602, 603, 604, 609, 611, 612, 613, 614, 619, 621, 622, 623, 624, 629, 501, 502, 509, 741, 742, 749, 591, 592, 593, 594]</td><td>M1 vehicle &
Opponent is a vehicle &
driving speed difference <= 70 km/h &
no ice and snow on road &
no poor road condition &
no unstable vehicle condition &
fine weather &
relevant accident types</td></tr>
<tr><td>AEB back-over</td><td>klassece == 1
artteil <= 4 | artteil == 7
v0 <= 30
nied == 2 & wolk ~=7 & (nebelm ~= [3, 4]
utyp == [571, 572, 711, 712, 714, 715]</td><td>M1 vehicle &
Opponent is a vehicle &
own driving speed <= 30 km/h &
fine weather &
relevant accident types</td></tr>
<tr><td>AEB pedestrian[1]</td><td>klassece == 1
v0 <= 40 & v0 >= 5
sichtbv ~= [1, 4]</td><td>M1 vehicle &
5 km/h <= own driving speed <= 40 km/h &
no visual obstruction &</td></tr>
</table>

[1] Only pedestrian accidents from table FGDAT are considered.

	fgvkol ~= [5,6]	Pedestrian not running &
	strob ~= [6,7]	no ice and snow on road &
	strzb ~= 4	no poor road condition &
	schleu == 2	no unstable vehicle condition &
	nied == 2 & wolk ~= 7 & nebelm ~= [3,4]	fine weather
AEB cyclist	klassece == 1	M1 vehicle &
	artteil == 5	opponent is a cyclist
	v0 <= 40 & v0 >= 5	5 km/h <= own driving speed <= 40 km/h &
	v0 <= 30	cyclist speed <= 30 km/h
	sichtbv ~= [1, 4]	no visual obstruction &
	strob ~= [6,7]	no ice and snow on road &
	strzb ~= 4	no poor road condition &
	schleu == 2	no unstable vehicle condition &
	nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])	fine weather
AEB animal	klassece == 1	M1 vehicle &
	utyp = [751, 752, 753, 759]	relevant accident types &
	v0 <= 40 & v0 >= 5	5 km/h <= own driving speed <= 40 km/h &
	sichtbv ~= [1, 4]	no visual obstruction &
	strob ~= [6,7]	no ice and snow on road &
	strzb ~= 4	no poor road condition &
	schleu == 2	no unstable vehicle condition &
	nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])	fine weather
AEB pedestrian reversing[1]	klassece == 1	M1 vehicle &
	utyp = [713]	relevant accident types &
	v0 <= 30	own driving speed <= 30 km/h &
	nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])	fine weather
AEB intersection	klassece == 1	M1 vehicle &
	artteil <= 4 | artteil == 7	Opponent is a vehicle &
	v0 <= 60	own and opponent driving speed <= 60 km/h &
	sichtbv ~= [1, 4]	no visual obstructions &
	strob ~= [6,7]	no ice and snow on road &
	strzb ~= 4	no poor road condition &
	schleu == 2	no unstable vehicle condition &
	nied == 2 & wolk ~=7 & (nebelm ~= [3, 4)	fine weather &
	utyp == [202, 232, 251, 252, 259, 211, 212, 281, 351, 354, 271, 301, 311, 321, 322, 331, 353, 355, 561, 562, 215, 261, 302, 312, 322, 332, 352, 303, 304, 213, 214, 262, 286, 306, 323, 324, 326, 333, 334, 313, 314]	relevant accident types
ISA (Intelligent Speed Adaptation)	klassece == 1	M1 vehicle &
	hursau = 12	Accident caused by speeding &
	strob ~= [6,7]	no ice and snow on road &
	strzb ~= 4	no poor road condition &
	schleu == 2	no unstable vehicle condition &
	nied == 2 & wolk ~=7 & (nebelm ~= [3, 4)	fine weather

[1] Only pedestrian accidents from table FGDAT are considered.

LCA (Lane Change Assist)	klassece == 1 (artteil <= 4 | artteil == 7) & klassece ~=8 v0 >= 60 & v0 < 500) mark == [1,3,4,5,6,7,8,10,11,12] strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & (wolk ~= 7 & nebelm ~= [3,4]) hursau ~= [12, 13] utyp = [204, 233, 305, 315, 635, 645, 646, 325, 553, 651, 652]	M1 vehicle & opponent is a vehicle & own driving speed >= 60 km/h & lane markings present & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather & accident not caused by speeding & relevant accident types
LKA (Lane Keep Assist)	klassece == 1 spverla = [1, 3, 4, 8] v0 >= 60 & v0 < 500 mark == [1,3,4,5,6,7,8,10,11,12] & strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & (wolk ~= 7 & nebelm ~= [3,4]) hursau ~= [12, 13]	M1 vehicle & unintentionally leaving lane before crash & own driving speed >= 60 km/h & markings present & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather accident not caused by speeding
ESC (Electronic Stability Control)	klassece == 1 schleu == 1 esp == 2 strob ~= [6,7] strzb ~= 4 nied == 2 & (wolk ~= 7 & nebelm ~= [3,4]) hursau ~= [12, 13] utyp == [101, 102, 109, 111, 112, 119, 121, 122, 123, 129, 131, 132, 139, 141, 151, 152, 153, 159, 161, 162, 163, 169, 171, 172, 173, 179, 181, 182, 183, 189, 199]	M1 vehicle & unstable vehicle condition & ESC not present & no ice and snow on road & no poor road condition & fine weather & accident not caused by speeding & relevant accident types
AEB V2X pedestrian[1]	klassece == 1 v0 <= 40 & v0 >= 5 fgvkol ~= [5,6] strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])	M1 vehicle & 5 km/h <= own driving speed <= 40 km/h & Pedestrian not running & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather
AEB V2X cyclist	klassece == 1 artteil == 5 v0 <= 40 & v0 >= 5 v0 <= 30 strob ~= [6,7] strzb ~= 4 schleu == 2	M1 vehicle & Opponent is a cyclist 5 km/h <= own driving speed <= 40 km/h & Cyclist speed <= 30 km/h no ice and snow on road & no poor road condition & no unstable vehicle condition &

[1] Only pedestrian accidents from table FGDAT are considered.

	nied == 2 & (wolk ~= 7 & nebelm ~= [3,4])	fine weather
AEB V2X intersection	klassece == 1 artteil <= 4 | artteil == 7 v0 <= 60 strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & (wolk ~=7 & (nebelm ~= [3, 4]) utyp = [202, 232, 251, 252, 259, 211, 212, 281, 351, 354, 271, 301, 311, 321, 322, 331, 353, 355, 561, 562, 215, 261, 302, 312, 322, 332, 352, 303, 304, 213, 214, 262, 286, 306, 323, 324, 326, 333, 334, 313, 314]	M1 vehicle & Opponent is a vehicle & own and opponent driving speed <= 60 km/h & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather & relevant accident types
Safety-minded driving	klassece == 1 strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & (wolk ~= 7 & nebelm ~= [3,4]) hursau == [1, 2, 10, 11, 12, 16, 17, 18, 19, 24, 25, 27, 28, 29, 30, 31, 32, 33, 38, 43, 44, 45, 46, 50, 51, 52, 53, 54, 55]	M1 vehicle & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather & relevant accident causation
Cautious driving	klassece == 1 strob ~= [6,7] strzb ~= 4 schleu == 2 nied == 2 & wolk ~= 7 & nebelm ~= [3,4] hursau == [3,4, 13, 14,15, 20, 21, 22, 23, 26, 39, 40, 41, 42, 47, 48, 70, 71, 72, 73, 74, 75, 80, 81, 82, 83, 84, 85, 86, 87, 88]	M1 vehicle & no ice and snow on road & no poor road condition & no unstable vehicle condition & fine weather relevant accident causation

APPENDIX B:
Passive safety and ADAS technologies fatality prevention optimistic rulesets

Technology	Conservative ruleset using GIDAS variables	Ruleset in text
Seat-belt reminder	klassece == 1 rhsben == [2,9] vdi6 <= 3 & vdi6 >= 0	M1 vehicle & belt not used or unknown & non-catastrophic vehicle damage
Frontal airbags	klassece == 1 vdi2 == 1 airbf == [0,9] sreihe == 1 & (squer == 1 | squer == 9) (ais98reg1 ~= 0 | ais98reg2 ~= 0) (vdi6 <= 3 & vdi6 >= 0) | isnan(vdi6)	M1 vehicle & frontal impact & airbag not present or unknown & first-row occupant & injury to head present or unknown & non-catastrophic vehicle damage
Side airbags	klassece == 1 vdi2 == [2,4] airbdi == [0,9] |airbsi == [0,9] |airbti == [0,9] squer == 1 | squer == 9 (vdi6 <= 3 & vdi6 >= 0) | isnan(vdi6)	M1 vehicle & Side impact & side airbags not present or unknown & occupant seated in outer position & non-catastrophic vehicle damage
Improved airbags	klassece == 1 airbf == [1,2,9] sreihe == 1 & (squer == 1 | squer == 9) ais98reg1 ~= 0 | ais98reg2 ~= 0) (vdi6 <= 3 & vdi6 >= 0) | isnan(vdi6)	M1 vehicle & frontal airbag present or unknown & first-row occupant & injury to head present or unknown & non-catastrophic vehicle damage
AEB rear-end	klassece == 1 artteil <= 4 | artteil == 7 (v0-v0_opp <= 100) | v0 > 800 utyp = [201, 231, 541, 542, 549, 583, 584, 601, 602, 603, 604, 609, 611, 612, 613, 614, 619, 621, 622, 623, 624, 629, 501, 502, 509, 741, 742, 749, 591, 592, 593, 594]	M1 vehicle & opponent is a vehicle & driving speed difference <= 100 km/h & relevant accident types
AEB back-over	klassece == 1 (artteil <= 4 | artteil == 7) & klassece_opp ~=8 v0 <= 30 utyp = [571, 572, 711, 712, 714, 715]	M1 vehicle & opponent is a vehicle & own driving speed <= 30 km/h & relevant accident types
AEB pedestrian[1]	klassece == 1 v0 <= 60 sichtbv ~= [1, 4]	M1 vehicle & own driving speed <= 60 km/h & no visual obstruction
AEB cyclist	klassece == 1 artteil == 5 v0 <= 60 sichtbv ~= [1, 4]	M1 vehicle & Opponent is a cyclist own driving speed <= 60 km/h & no visual obstruction

[1] Only pedestrian accidents from table FGDAT are considered.

<table>
<tr><td>AEB animal</td><td>klassece == 1
v0 <= 60
sichtbv ~= [1, 4]
utyp = [751, 752, 753, 759]</td><td>M1 vehicle &
own driving speed <= 60 km/h &
no visual obstruction &
relevant accident type</td></tr>
<tr><td>AEB pedestrian reversing[1]</td><td>klassece == 1
v0 <= 30
utyp = [713]</td><td>M1 vehicle &
own driving speed <= 30 km/h &
relevant accident type</td></tr>
<tr><td>AEB intersection</td><td>klassece == 1
artteil <= 4 | artteil == 7
v0 <= 60

sichtbv ~= [1, 4]
utyp == [202, 232, 251, 252, 259, 211, 212, 281, 351, 354, 271, 301, 311, 321, 322, 331, 353, 355, 561, 562, 215, 261, 302, 312, 322, 332, 352, 303, 304, 213, 214, 262, 286, 306, 323, 324, 326, 333, 334, 313, 314]</td><td>M1 vehicle &
opponent is a vehicle &
own and opposite driving speed <= 60 km/h &
no visual obstructions &
relevant accident types</td></tr>
<tr><td>ISA (Intelligent Speed Adaptation)</td><td>klassece == 1
hursau = 12</td><td>M1 vehicle &
accident caused by over-speeding</td></tr>
<tr><td>LCA (Lane Change Assist)</td><td>klassece == 1
(artteil <= 4 | artteil == 7) & klassece_opp ~=8
v0 >= 60
utyp == [204, 233, 305, 315, 635, 645, 646, 325, 553, 651, 652]</td><td>M1 vehicle &
opponent is a vehicle &
own driving speed >= 60 km/h &
relevant accident types</td></tr>
<tr><td>LKA (Lane Keep Assist)</td><td>klassece == 1
spverla = [1, 3, 4, 8]

v0 >= 60)</td><td>M1 vehicle &
unintentionally leaving lane before crash &
own driving speed >= 60 km/h</td></tr>
<tr><td>ESC (Electronic Stability Control)</td><td>klassece == 1
schleu == [1,99]
esp == [2,9]
utyp == [101, 102, 109, 111, 112, 119, 121, 122, 123, 129, 131, 132, 139, 141, 151, 152, 153, 159, 161, 162, 163, 169, 171, 172, 173, 179, 181, 182, 183, 189, 199]</td><td>M1 vehicle &
unstable or unknown vehicle condition &
ESC not present or unknown
& relevant accident types</td></tr>
<tr><td>AEB V2X pedestrian</td><td>klassece == 1
v0 <= 60</td><td>M1 vehicle &
own driving speed <= 60 km/h &</td></tr>
<tr><td>AEB V2X cyclist</td><td>klassece == 1
artteil == 5</td><td>M1 vehicle &
opponent is a cyclist</td></tr>
</table>

[1] Only pedestrian accidents from table FGDAT are considered.

	v0 <= 60	own driving speed <= 60 km/h
AEB V2X intersection	klassece == 1 artteil <= 4 | artteil == 7 v0 <= 60 utyp == [202, 232, 251, 252, 259, 211, 212, 281, 351, 354, 271, 301, 311, 321, 322, 331, 353, 355, 561, 562, 215, 261, 302, 312, 322, 332, 352, 303, 304, 213, 214, 262, 286, 306, 323, 324, 326, 333, 334, 313, 314]	M1 vehicle & opponent is a vehicle & own and opponent driving speed <= 60 km/h & relevant accident types
Safety-minded driving	klassece == 1 hursau == [1,2, 10, 11, 12, 16,17,18,19,24,25, 27,28,29,30,31,32,33, 38, 43, 44, 45, 46, 50, 51, 52, 53, 54, 55]	M1 vehicle & relevant accident causation
Cautious driving	klassece == 1 hursau == [3,4, 13, 14, 15, 20, 21, 22, 23, 26, 39, 40, 41, 42, 47, 48, 70, 71, 72, 73, 74, 75, 80, 81, 82, 83, 84, 85, 86, 87, 88]	M1 vehicle & relevant accident causation

APPENDIX C:
Flowchart of the coding process

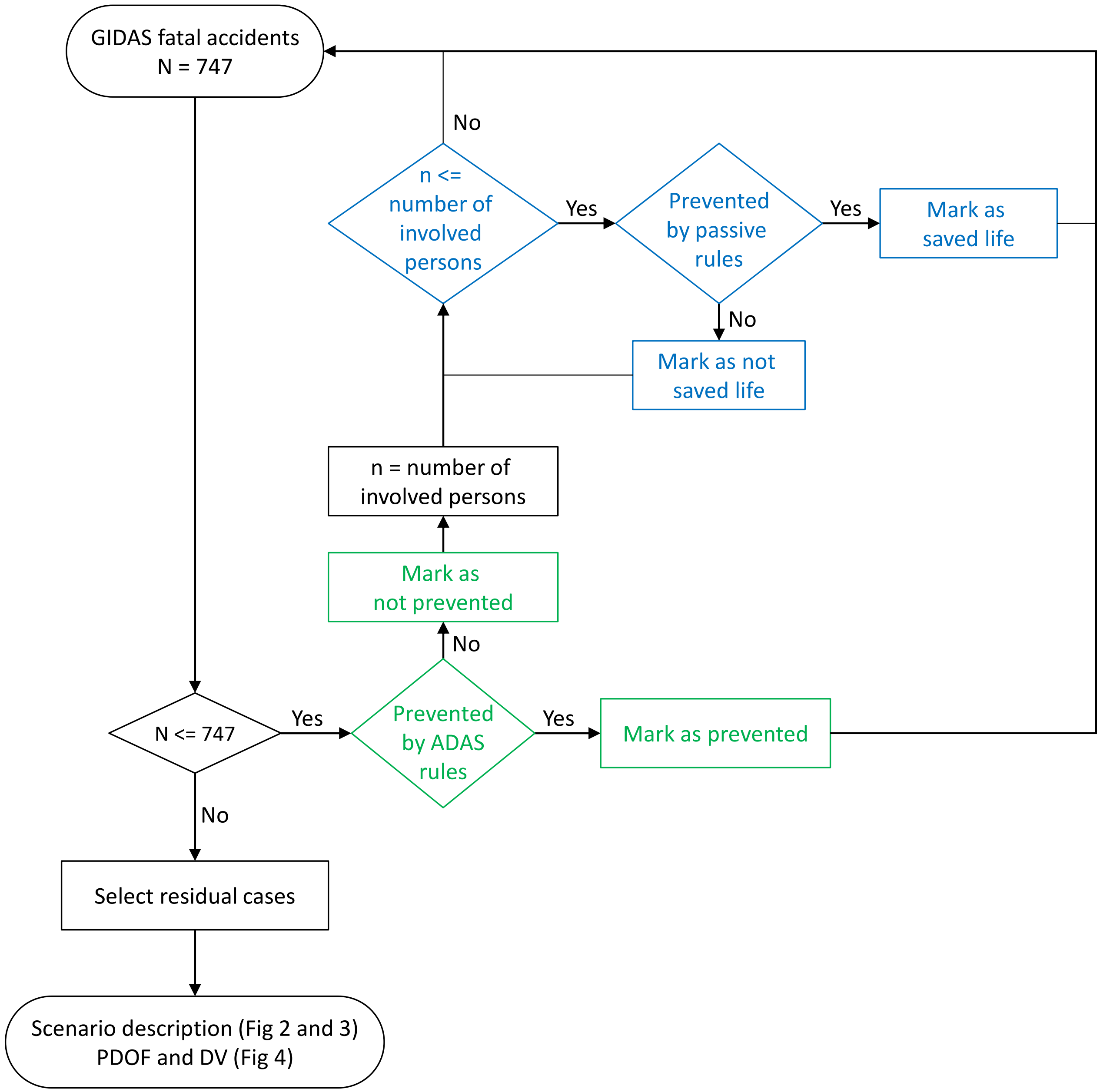
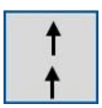
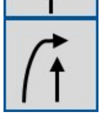
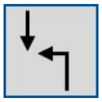
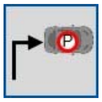
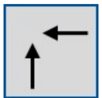
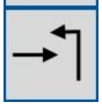
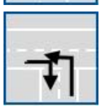
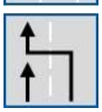
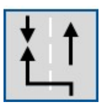
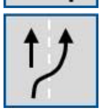
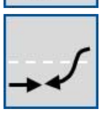
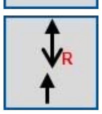
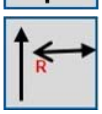
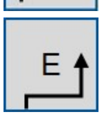
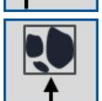
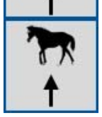
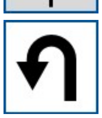


Fig. C1. Flowchart of the coding process. In green: accident level; in blue: person level

APPENDIX D:
Accident scenario classification

The classification of accident scenarios is based on several variables in GIDAS. *UTYP* describes the conflict situation leading to the accident according to *Gesamtverband der Deutschen Versicherungswirtschaft e.V., 2016, Unfalltypen-Katalog. Berlin, Germany*. *URSWIS* describes the accident causation as defined by the investigation team, according to official German federal definitions (see, for example, https://recht.nrw.de/lmi/owa/br_vbl_show_pdf?p_id=12224). *TECHMAN* = 1 denotes a suspected technical defect of the vehicle. *SCHLEU* = 1 denotes an unstable condition prior to the first collision. *SCHLEU* = 2 denotes a stable condition and other values an unknown condition. It should be noted that the code is hierarchical in the order of the table and categories are not mutually exclusive.

<table>
<tr><th>#</th><th></th><th>Name</th><th>Description</th><th>Code</th></tr>
<tr><td>1</td><td></td><td>Technical Failure</td><td>Vehicle sustains a technical failure with the consequence of a conflict situation</td><td>rec150$UTYP %in% c(771, 772, 773, 774, 775) | ((rec150$URSWIS1 %in% c(50, 51, 52, 53, 54, 55) | rec150$URSWIS2 %in% c(50, 51, 52, 53, 54, 55)) & rec150$TECHMAN==1)</td></tr>
<tr><td>2</td><td></td><td>Vehicle Loss of Control</td><td>Vehicle loses stability and is skidding with the consequence of a conflict situation</td><td>rec150$UTYP %in% c(101, 102, 109, 111, 112, 119, 121, 122, 123, 129, 131, 132, 139, 141, 151, 152, 153, 159, 161, 162, 163, 169, 171, 172, 173, 179, 181, 182, 183, 189, 199) & rec150$SCHLEU==1</td></tr>
<tr><td>3</td><td></td><td>Driver Loss of Control</td><td>Driver loses control over the vehicle with the consequence of a conflict situation</td><td>rec150$UTYP %in% c(101, 102, 109, 111, 112, 119, 121, 122, 123, 129, 131, 132, 139, 141, 151, 152, 153, 159, 161, 162, 163, 169, 171, 172, 173, 179, 181, 182, 183, 189, 199) & (rec150$SCHLEU==2 | rec150$SCHLEU==97 | rec150$SCHLEU==99)</td></tr>
<tr><td>4</td><td></td><td>Driver Incapacity</td><td>Driver is in drowsy or other physically impaired condition with the consequence of a conflict situation</td><td>rec150$UTYP %in% c(761, 762, 763)</td></tr>
<tr><td>5</td><td></td><td>Straight On-Path / Same direction</td><td>Straight heading on-path vehicle is in conflict with a vehicle ahead</td><td>rec150$UTYP %in% c(201, 231, 541, 542, 549, 583, 584, 601, 602, 603, 604, 609, 611, 612, 613, 614, 619, 621, 622, 623, 624, 629)</td></tr>
<tr><td>6</td><td></td><td>Straight On-Path / Pedestrian Longitudinal</td><td>Straight heading on-path vehicle is in conflict with a pedestrian moving in same or opposite direction</td><td>rec150$UTYP %in% c(671, 672, 673, 674)</td></tr>
<tr><td>7</td><td></td><td>Straight On-Path / VRU Crossing</td><td>Straight heading on-path vehicle is in conflict with a pedestrian crossing the roadway</td><td>rec150$UTYP %in% c(272, 274, 341, 342, 343, 344, 349, 361, 362, 363, 364, 369, 371, 372, 379, 401, 402, 403, 404, 405, 409, 411, 412, 413, 414, 419, 421, 422, 423, 424, 429, 431, 432, 433, 434, 435, 436, 439, 441, 442, 443, 444, 449, 451, 452, 453, 454, 455, 459, 461, 462, 463, 464, 465, 469, 471, 472, 473, 479, 491, 492, 493, 494, 499)</td></tr>
<tr><td>8</td><td></td><td>Straight On-Path / Parked Vehicle</td><td>Straight heading on-path vehicle is in conflict with a parked vehicle</td><td>rec150$UTYP %in% c(501, 502, 509, 581, 582, 589, 741, 742, 749)</td></tr>
<tr><td>9</td><td></td><td>Turn Across Path / Same Direction</td><td>Vehicle turning across path is in conflict with another vehicle moving in same direction</td><td>rec150$UTYP %in% c(202, 203, 232)</td></tr>
<tr><td>10</td><td></td><td>Turn Off-Path / Same Direction</td><td>Vehicle turning off-path is in conflict with another vehicle moving in same direction</td><td>rec150$UTYP %in% c(251, 252, 259)</td></tr>
</table>

11		Left (Right) Turn Across Path / Opposite Direction	Vehicle turning left across path is in conflict with another vehicle moving in opposite direction	rec150$UTYP %in% c(211, 212, 281, 351, 354, 543)
12		Turn On-Path / VRU Crossing	Vehicle turning on-path is in conflict with VRU crossing roadway	rec150$UTYP %in% c(221, 222, 223, 224, 225, 229, 241, 242, 243, 244, 245, 249, 282, 283, 284, 285, 273, 275, 481, 482, 483, 484, 489)
13		Turn On-Path / Parked Vehicle	Vehicle turning on-path is in conflict with another parked vehicle	rec150$UTYP %in% c(591, 592, 593, 594)
14		Straight Crossing Path	Straight crossing path vehicles are in conflict with each other	rec150$UTYP %in% c(271, 301, 311, 321, 331, 353, 355)
15		Left (Right) Turn Across Path / Lateral Direction	Vehicle turning left across path is in conflict with another lateral vehicle	rec150$UTYP %in% c(215, 261, 302, 312)
16		Left (Right) Turn Into Path / Lateral Direction	Vehicle turning left into path is in conflict with another lateral vehicle	rec150$UTYP %in% c(322, 332, 352)
17		Right (Left) Turn Into Path / Lateral Direction	Vehicle turning right into path is in conflict with another lateral vehicle	rec150$UTYP %in% c(303, 304, 213, 214)
18		Turn Off-Path / Lateral direction	Vehicle turning off-path is in conflict with another lateral vehicle	rec150$UTYP %in% c(262, 286, 306, 323, 324, 326, 333, 334)
19		Lane Change / Same Direction	Vehicle changing lane is in conflict with another vehicle moving in same direction	rec150$UTYP %in% c(204, 233, 305, 313, 314, 315, 373, 374, 551, 552, 559, 631, 632, 633, 634, 635, 639, 641, 642, 643, 644, 645, 646, 649, 663)
20		Lane Change / Opposite Direction	Vehicle changing lane is in conflict with another vehicle moving in opposite direction	rec150$UTYP %in% c(325, 335, 661, 662, 664, 553, 554)
21		Lane Departure / Same Direction	Vehicle departing lane is in conflict with other vehicle moving in same direction	rec150$UTYP %in% c(651, 652, 659)
22		Lane Departure / Opposite direction	Vehicle departing lane is in conflict with other vehicle moving in same direction	rec150$UTYP %in% c(681, 682, 683, 689)
23		Backing-Up / Opposite Direction	Vehicle reversing is in conflict with another vehicle moving in opposite direction	rec150$UTYP %in% c(711, 712)
24		Backing-Up / Lateral Direction	Vehicle reversing is in conflict with another vehicle moving in lateral direction	rec150$UTYP %in% c(571, 572, 579, 713, 714, 715)
25		Evasive Maneuver	Vehicle making evasive manoeuvre is in conflict with other vehicle	rec150$UTYP %in% c(511, 512, 519, 521, 531, 532, 533, 534, 539)
26		Object On Road	Vehicle is in conflict with an object on road	rec150$UTYP %in% c(731, 732)
27		Animal On Road	Vehicle is in conflict with an animal standing on or crossing roadway	rec150$UTYP %in% c(751, 752, 753, 759)
28		U-Turn	Vehicle making a U-turn is in conflict with another vehicle	rec150$UTYP %in% c(721, 722, 723, 724, 729)

29		Parking	Vehicles are in conflict at a parking area	rec150$UTYP %in% c(, 561, 562, 569, 701, 702, 703, 709)
30		Other	Other kind of conflicts	rec150$UTYP %in% c(209, 219, 239, 279, 299, 359, 399, 599, 669, 679, 699, 719, 799)

APPENDIX E:
Initial sample fatalities and lives saved by step and road-user type, optimistic and conservative estimates

M1 vehicles equipped

	step 0	step 1		step 2		step 3		step 4		step 5	
		opt.	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*
passenger car	408	105	95	268	162	268	162	305	188	356	242
truck	37	0	0	3	3	3	3	4	4	5	5
bus	2	0	0	0	0	0	0	0	0	0	0
motorcycle	118	0	0	15	13	15	13	35	31	39	37
bicycle	72	0	0	22	15	26	17	35	31	37	33
pedestrian	168	0	0	56	21	56	21	61	28	72	47
tram	0	0	0	0	0	0	0	0	0	0	0
other	1	0	0	0	0	0	0	0	0	0	0
unknown	4	0	0	4	4	4	4	4	4	4	4

All vehicles equipped

	step 0	step 1		step 2		step 3		step 4		step 5	
		opt.	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*	*opt.*	*cons.*
passenger car	408	106	96	279	173	279	173	318	200	368	255
truck	37	9	7	29	25	29	25	30	26	33	27
bus	2	1	1	1	1	1	1	1	1	1	1
motorcycle	118	0	0	44	27	45	28	72	52	83	65
bicycle	72	0	0	35	26	40	29	48	43	49	44
pedestrian	168	0	0	116	36	120	37	122	46	126	68
tram	0	0	0	0	0	0	0	0	0	0	0
other	1	0	0	0	0	0	0	0	0	0	0
unknown	4	0	0	4	4	4	4	4	4	4	4

APPENDIX F:
Collision partner. Figures for all steps with conservative and optimistic estimates.

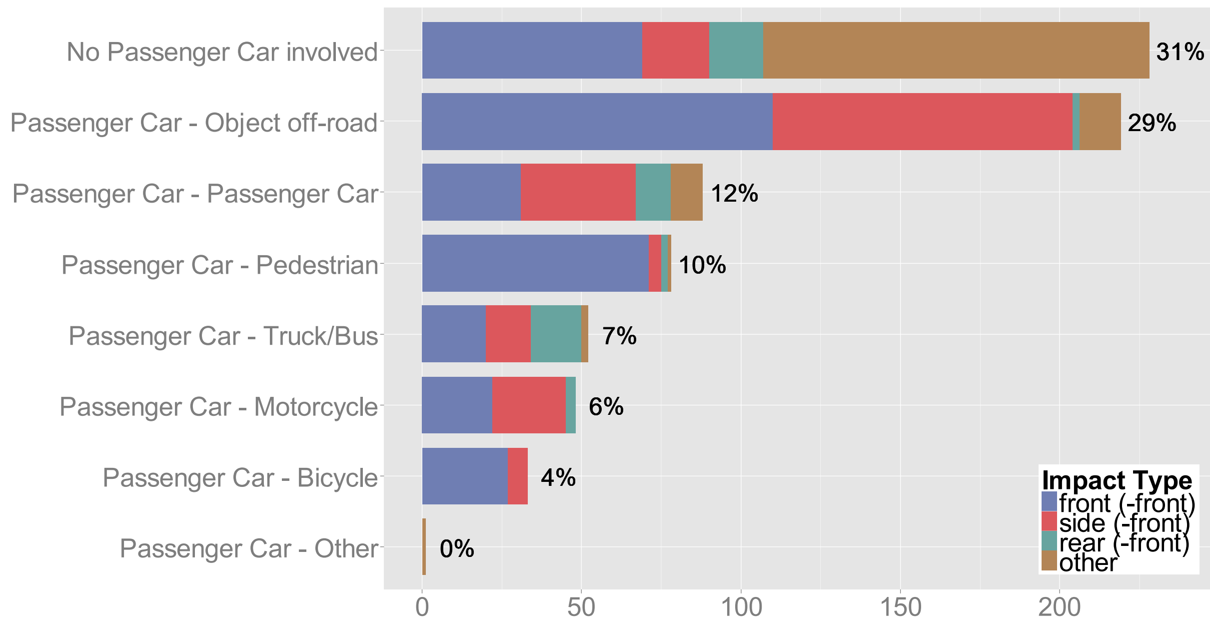


Fig. F1. Step 0 fatal accidents, N=747.

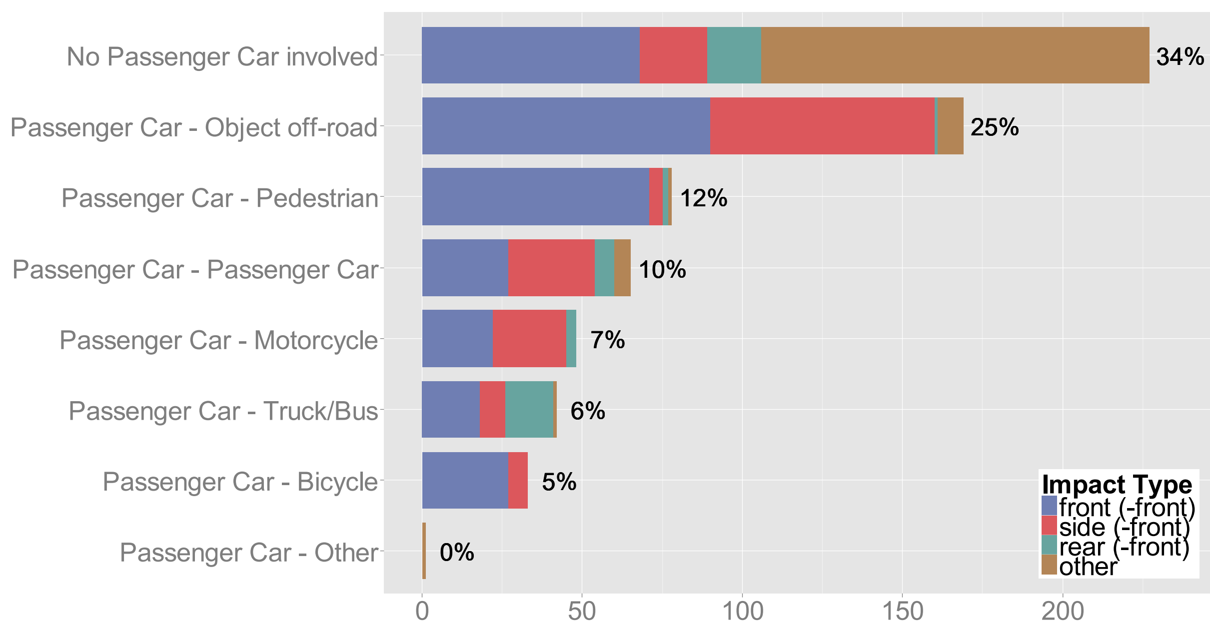


Fig. F2. Step1 conservative, N=663.

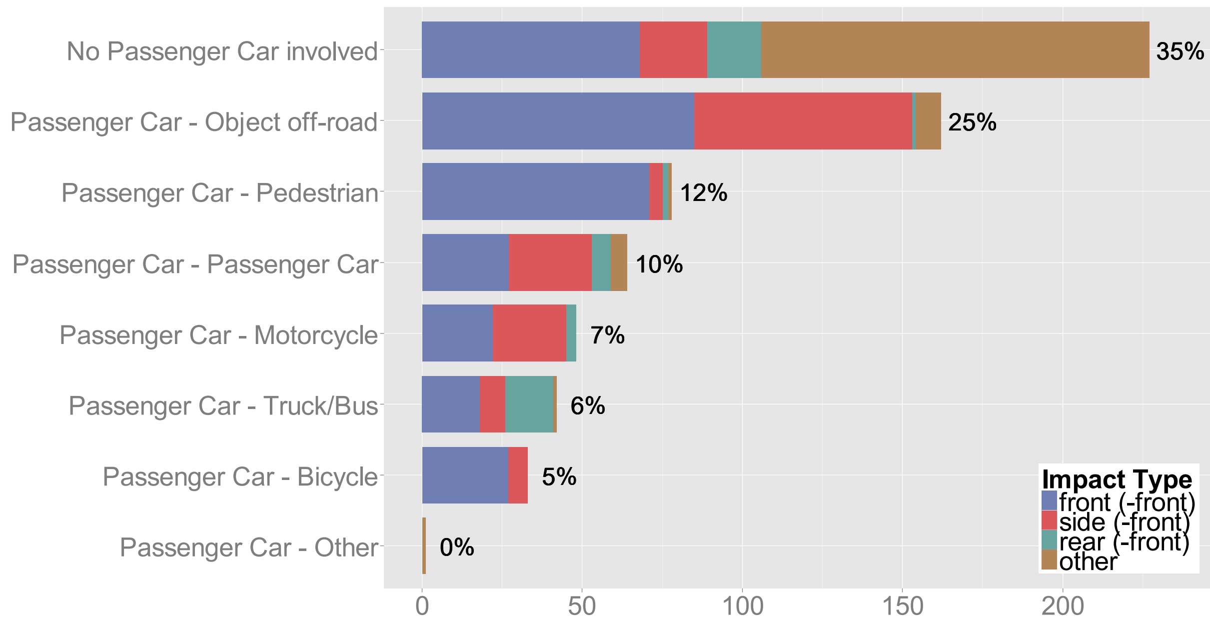


Fig. F3. Step1 optimistic, N=655.

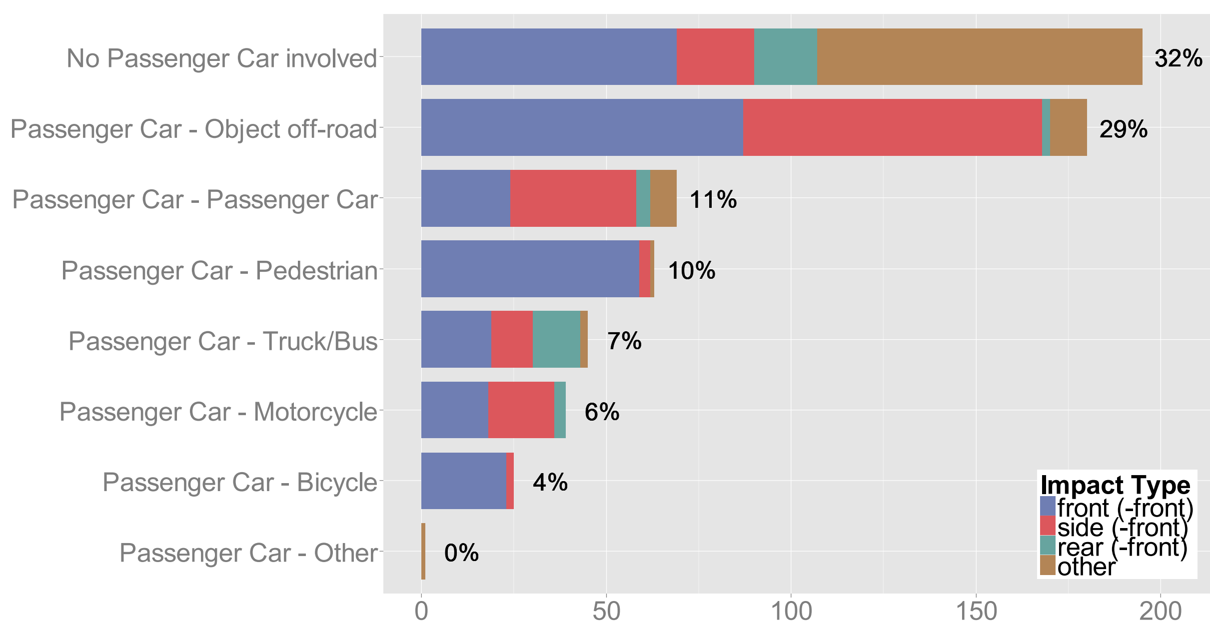


Fig. F4. Step2 conservative, N=617.

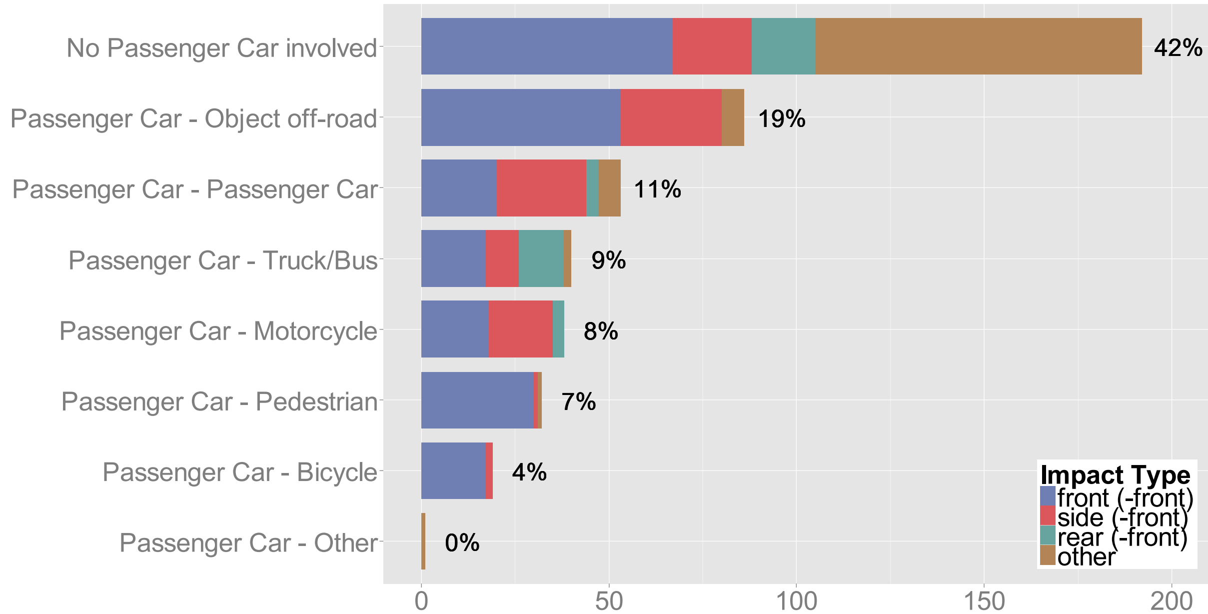


Fig. F5. Step2 optimistic, N=461.

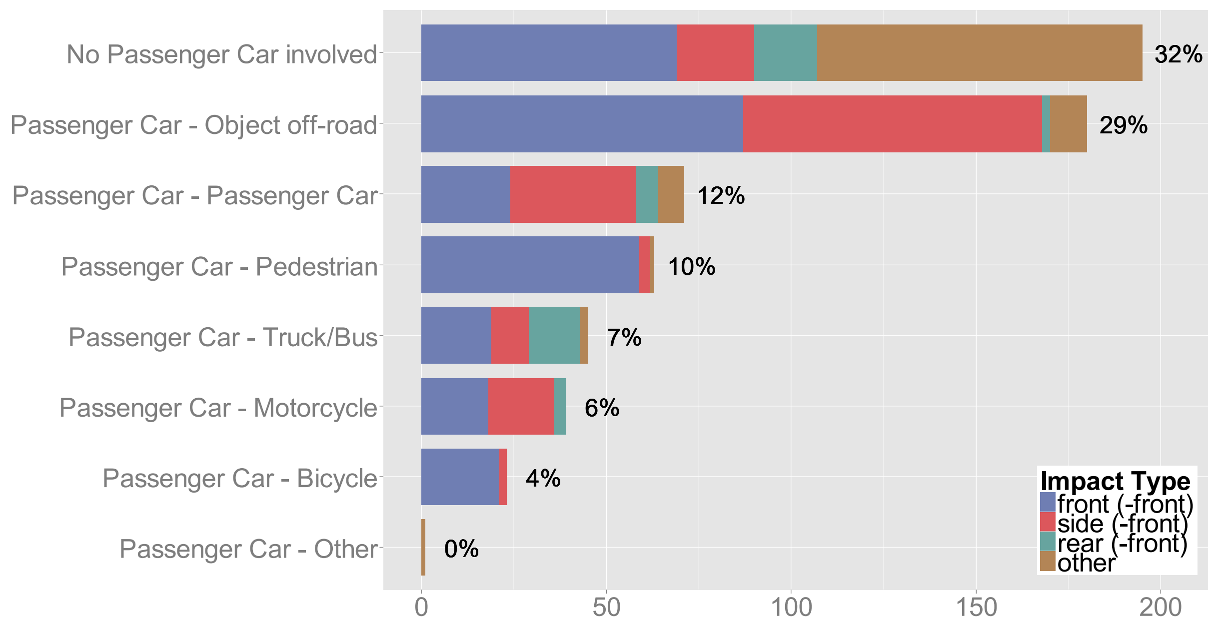


Fig. F6. Step3 conservative, N=617.

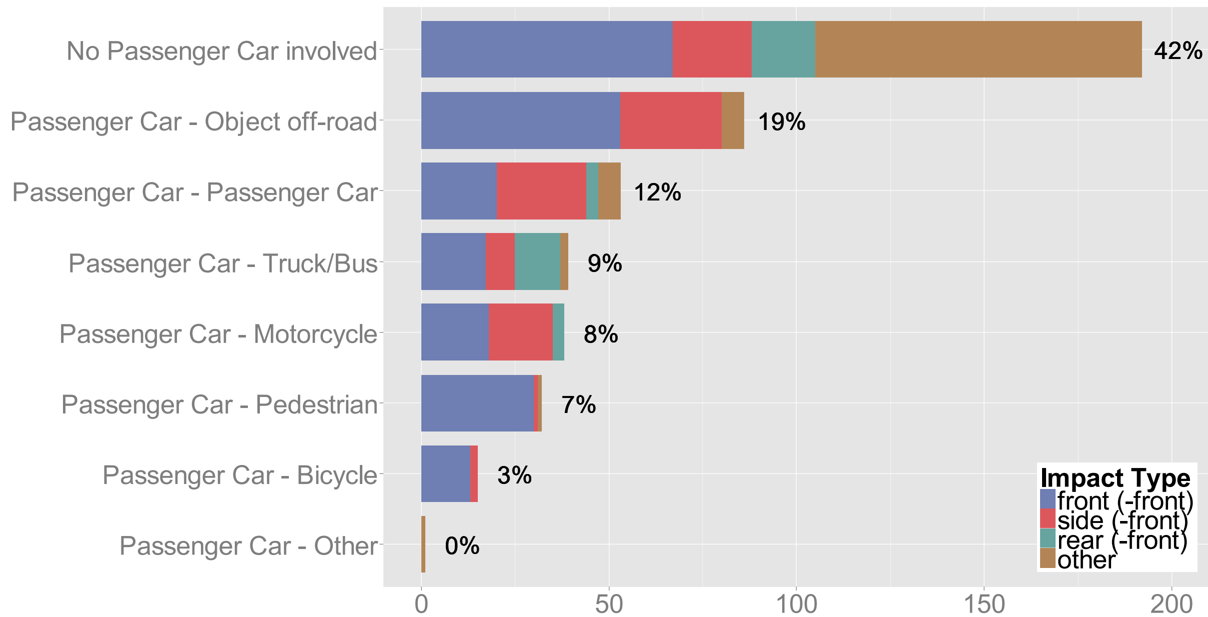


Fig. F7. Step 3 optimistic, N=456.

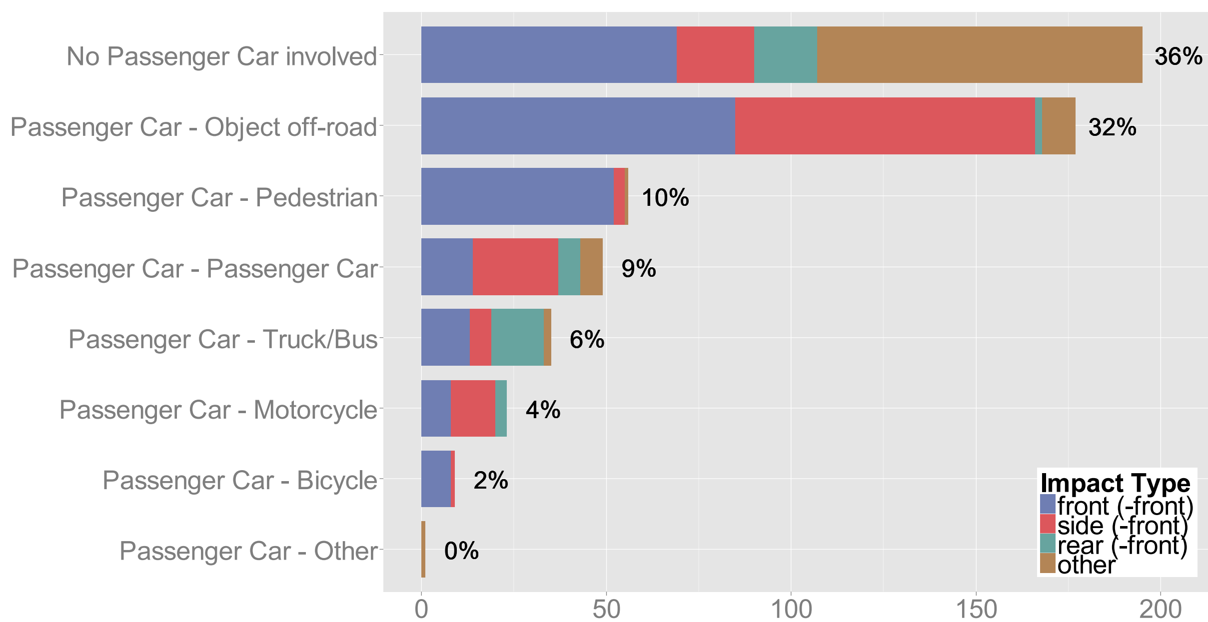


Fig. F8. Step 4 conservative, N=545.

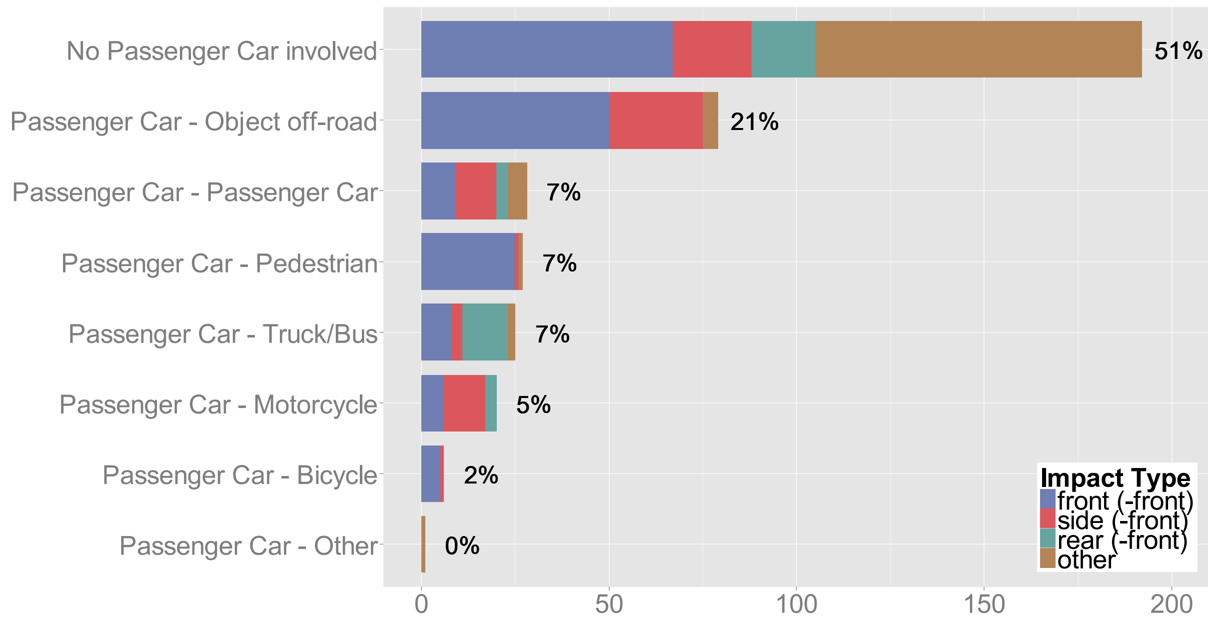


Fig. F9. Step 4 optimistic, N=378.

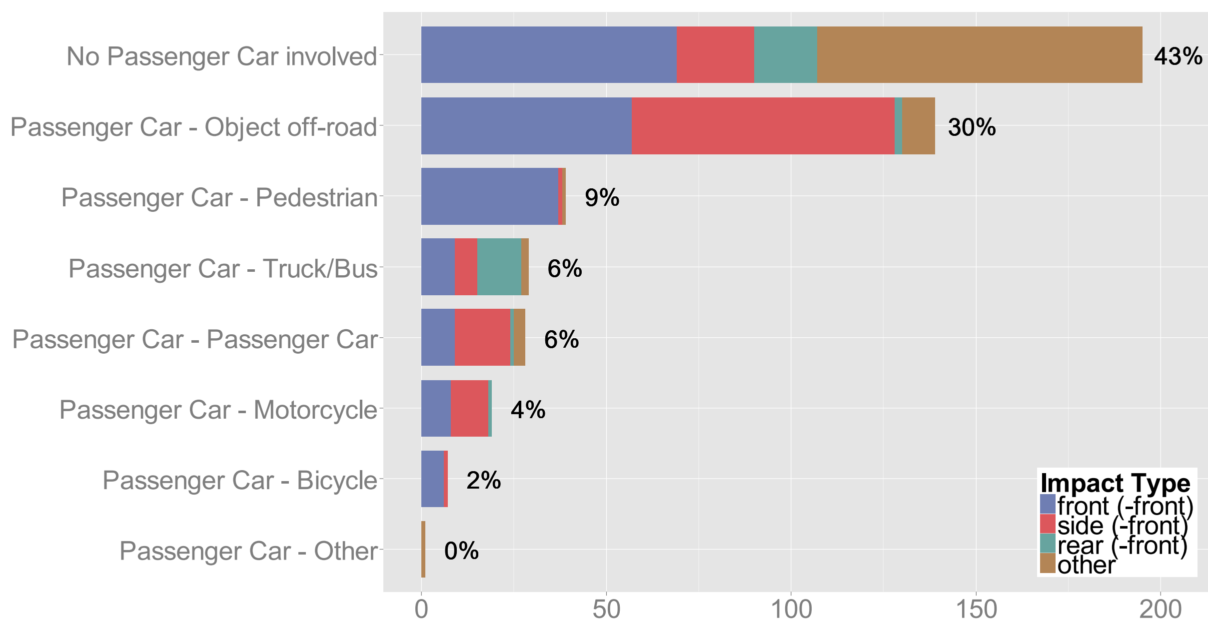


Fig. F10. Step 5 conservative, N=457.

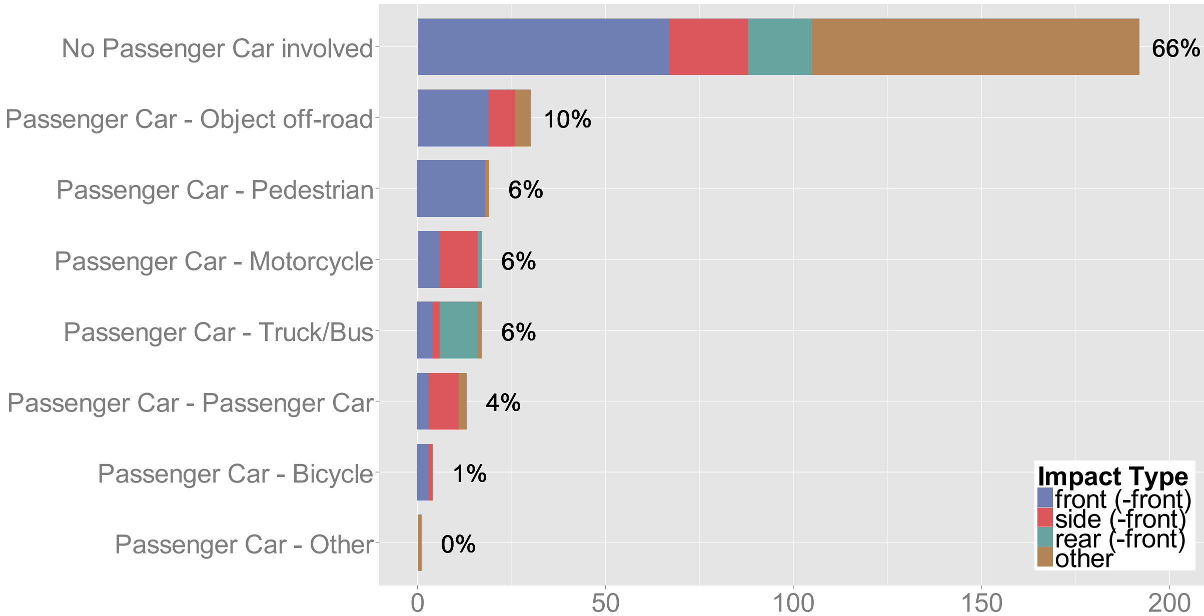


Fig. F11. Step 5 optimistic, N=293.

APPENDIX G:

Top 10 accident scenarios for M1 vehicles. Figures for all steps with conservative and optimistic estimates.

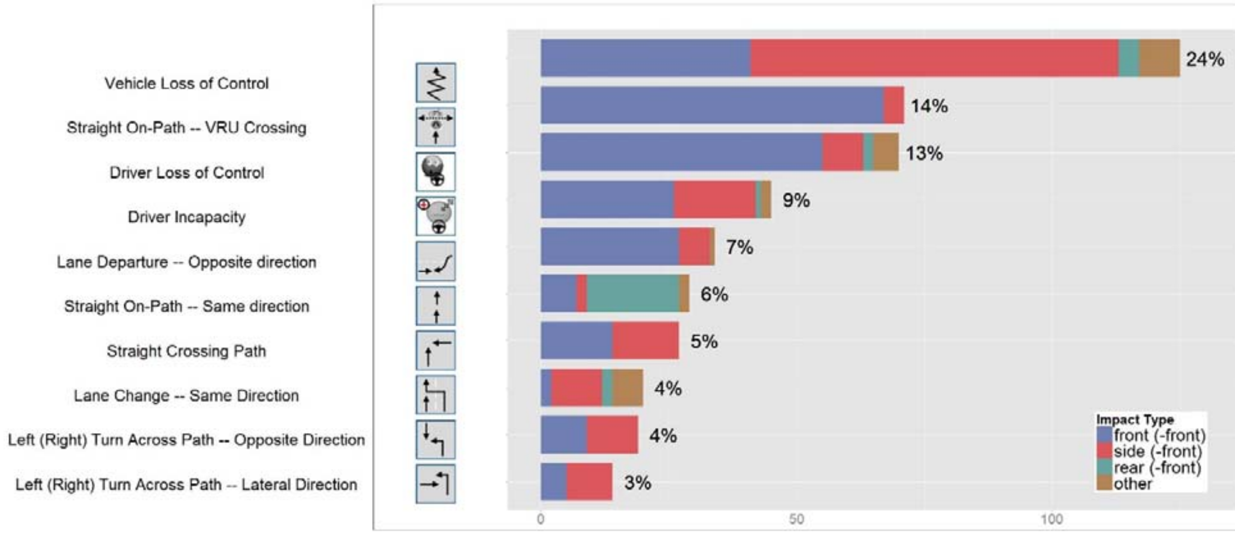


Fig. G1. Step 0 fatal accidents, N=519.

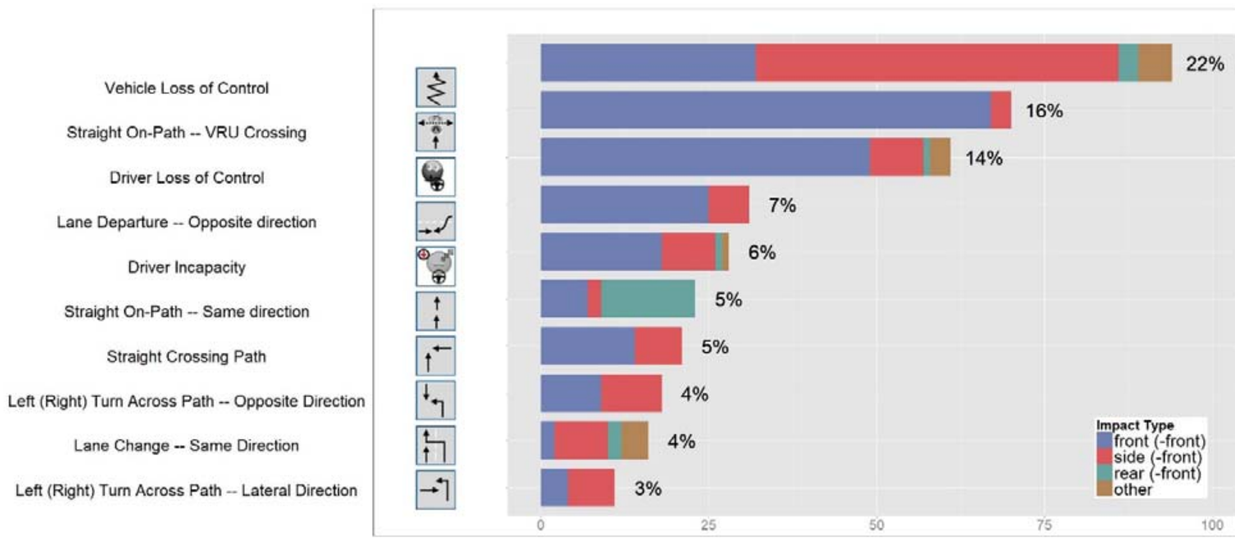


Fig. G2. Step 1 conservative, N=436.

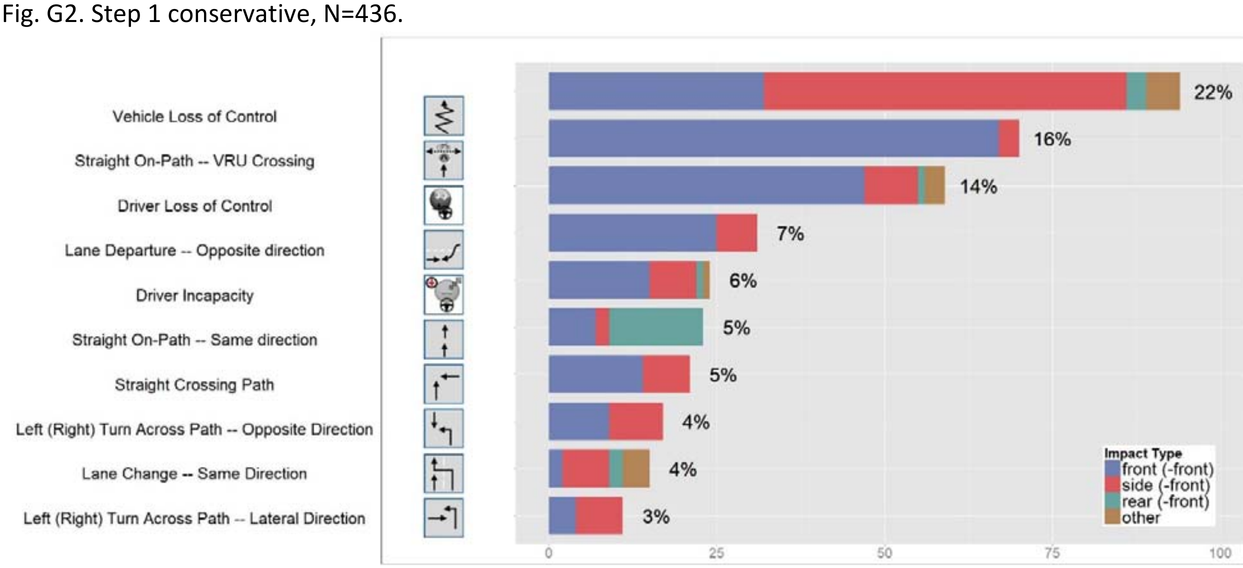


Fig. G3. Step 1 optimistic, N=467.

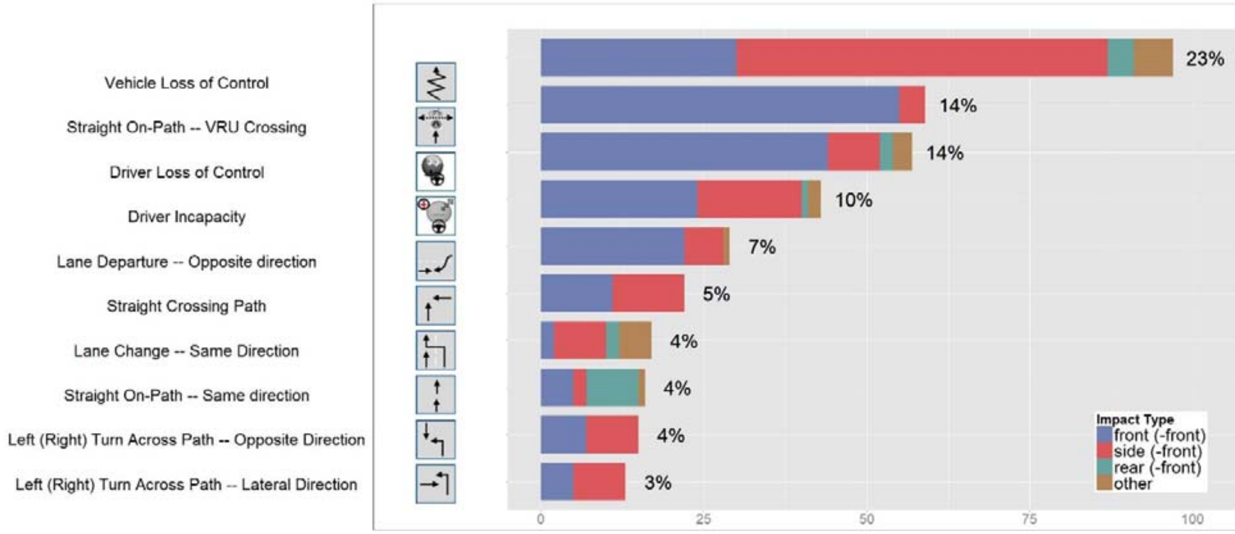


Fig. G4. Step 2 conservative, N=422.

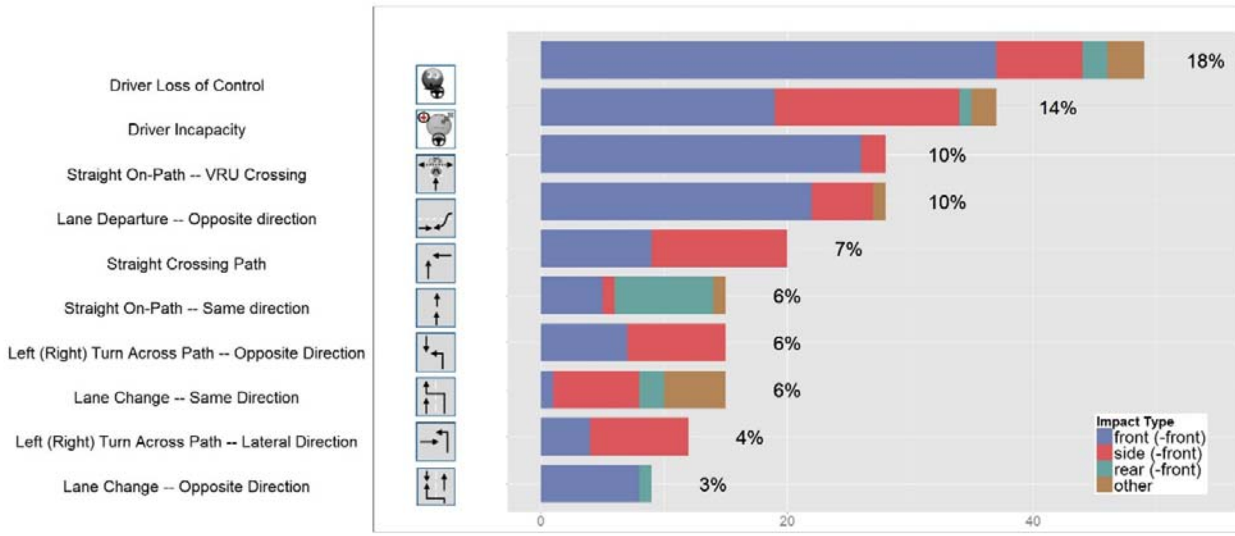


Fig. G5. Step 2 optimistic, N=269.

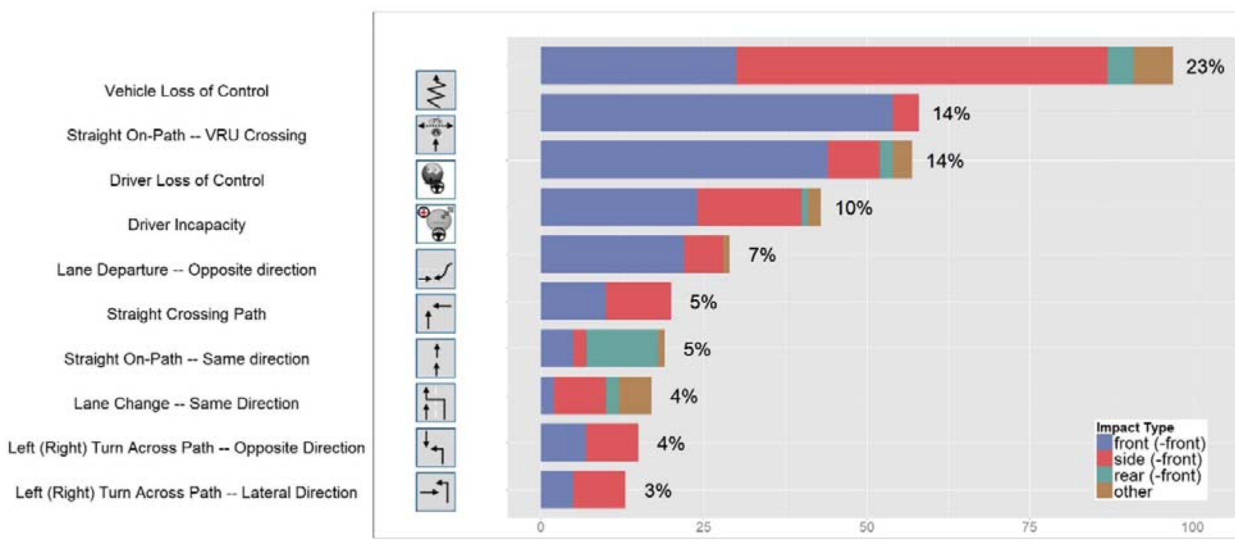


Fig. G6. Step 3 conservative, N=422.

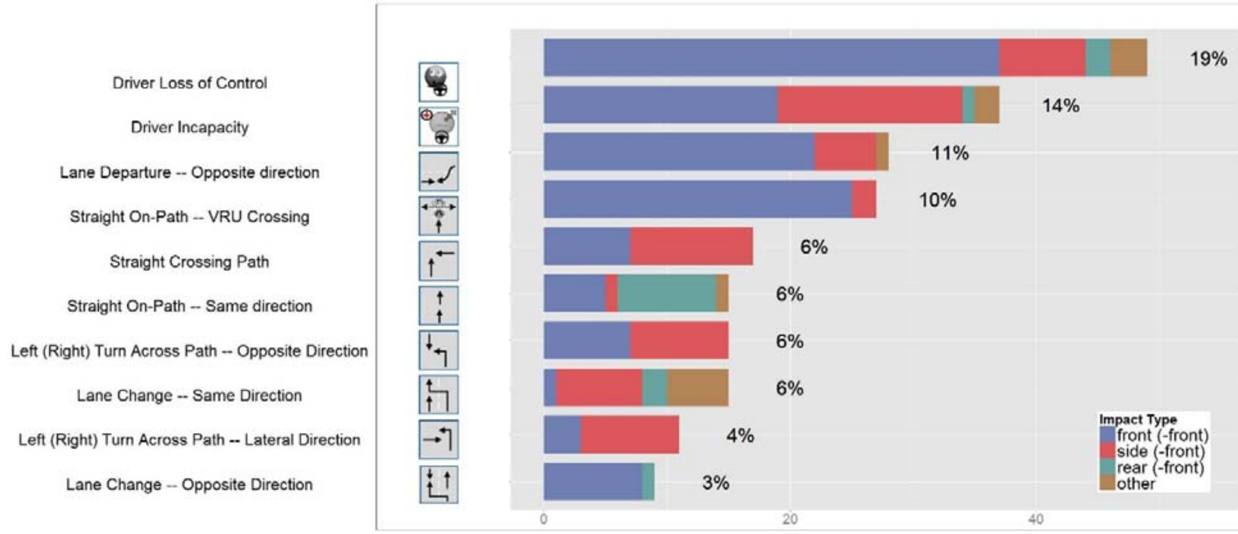


Fig. G7. Step 3 optimistic, N=264.

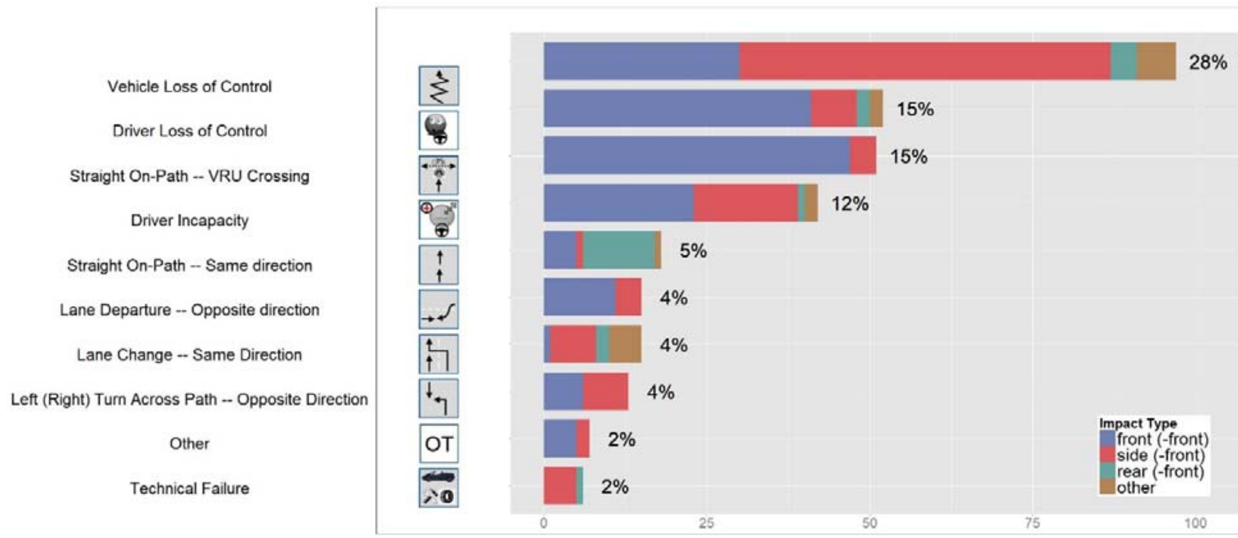


Fig. G8. Step 4 conservative, N=350.

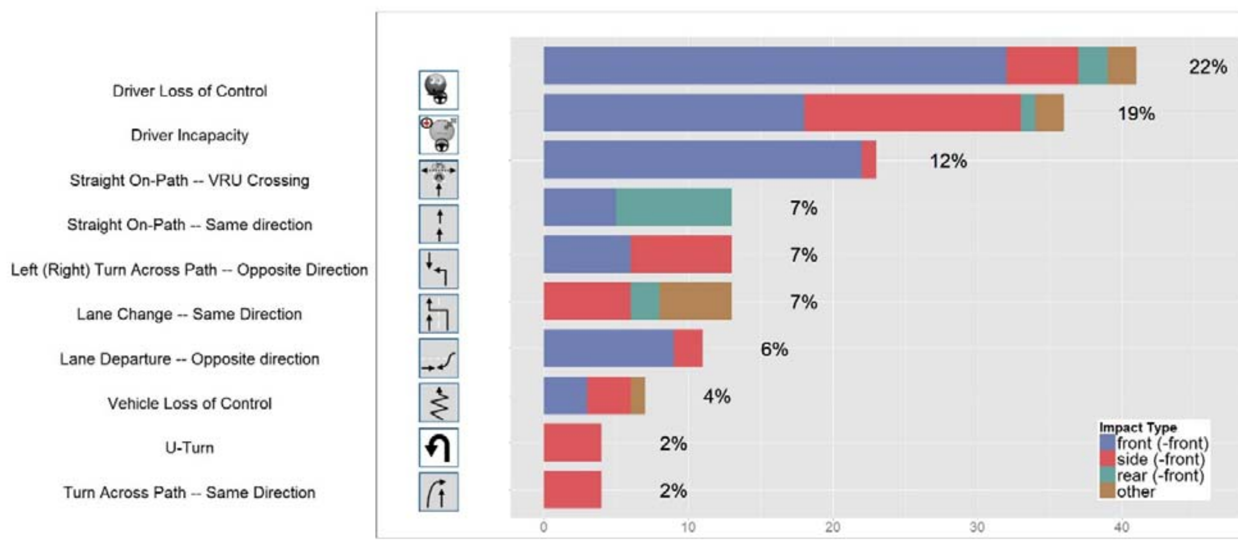


Fig. G9. Step 4 optimistic, N=186.

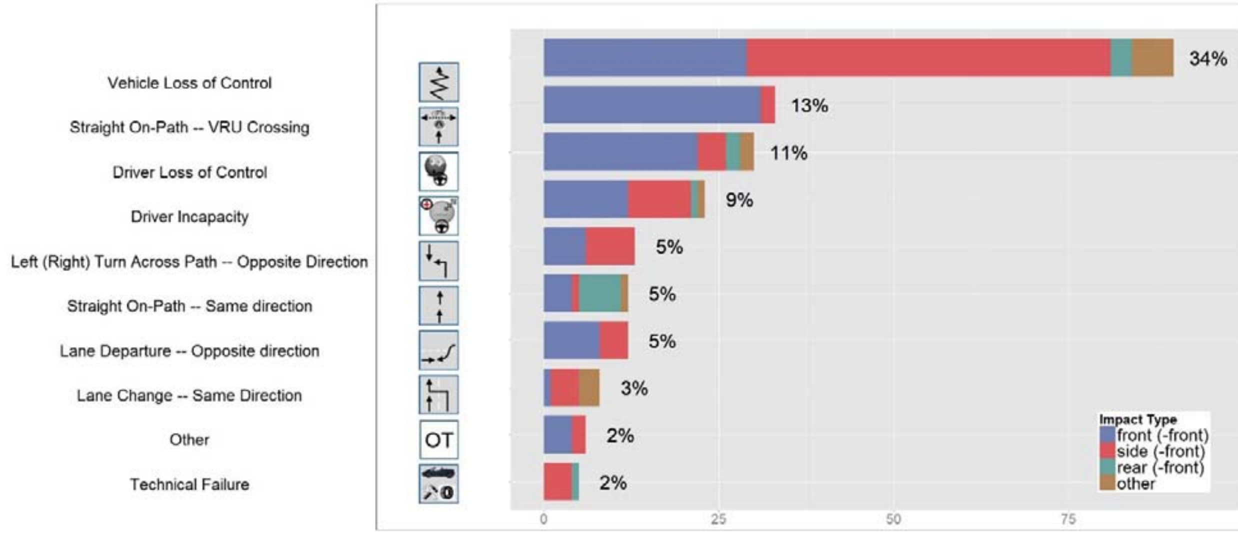


Fig. G10. Step 5 conservative, N=262.

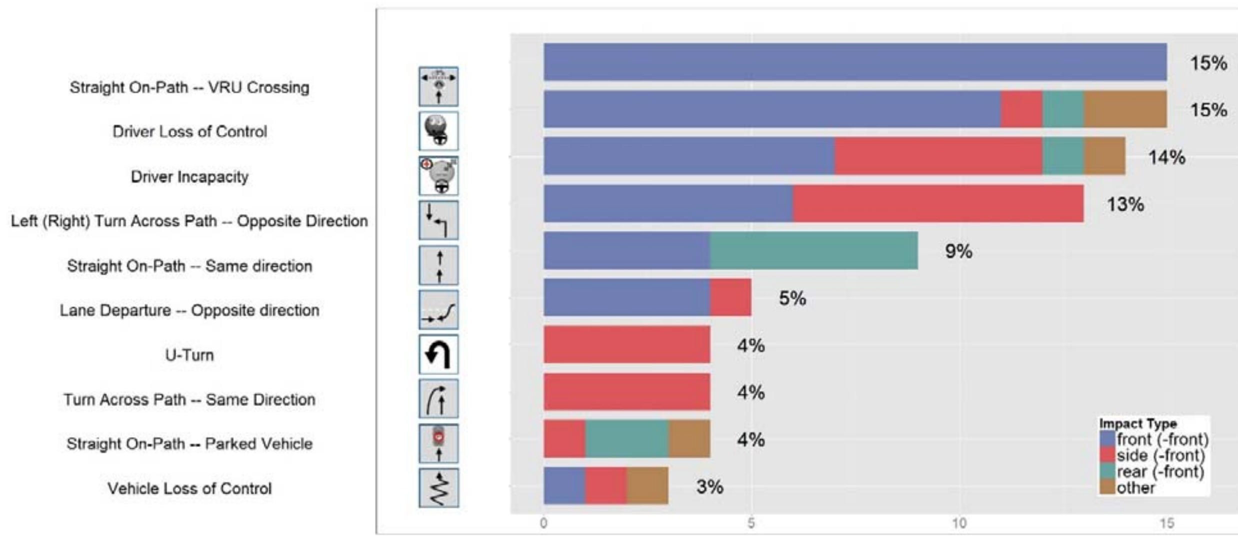


Fig. G11. Step 5 optimistic, N=101.

APPENDIX H:

DV and PDOF for all steps, with conservative and optimistic estimates.

The detailed rules on how systems were modelled and remaining crashes were determined are presented in Appendix A and B. Delta-v and PDOF are variables describing the remaining crashes, they were not used to determine the remaining crashes. Figures G1-G7 show how delta-v and PDOF distribute in all steps.

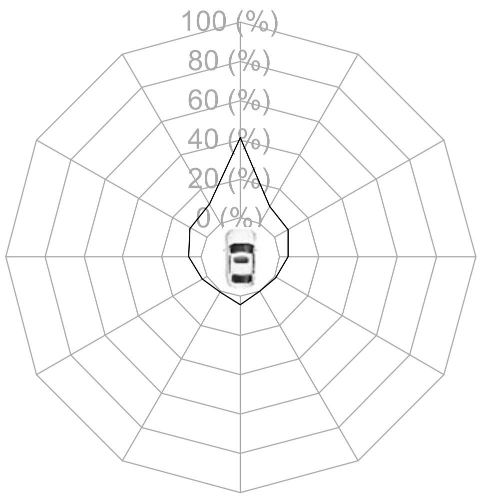


Fig. H1. Step 0.

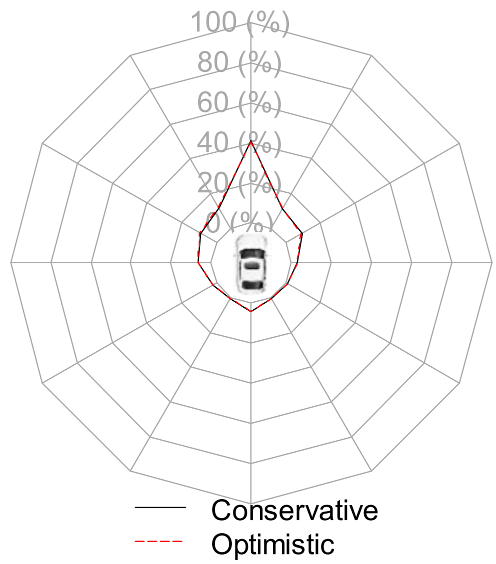


Fig. H2. Step 1.

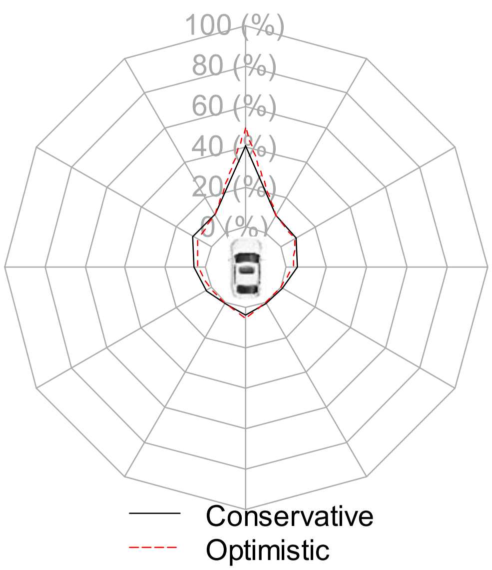


Fig. H3. Step 2.

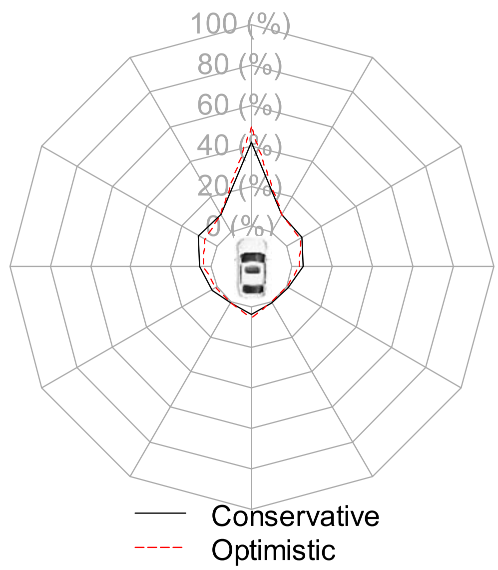


Fig. H4. Step 3.

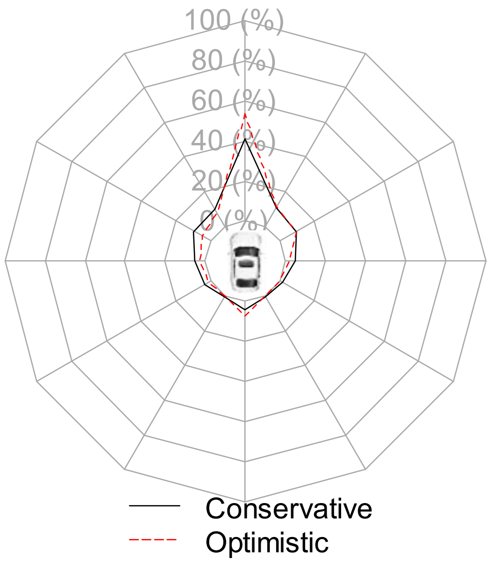


Fig. H5. Step 4.

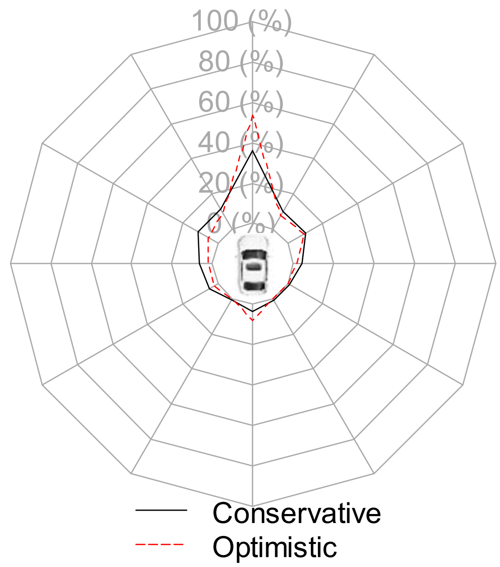


Fig. H6. Step 5.

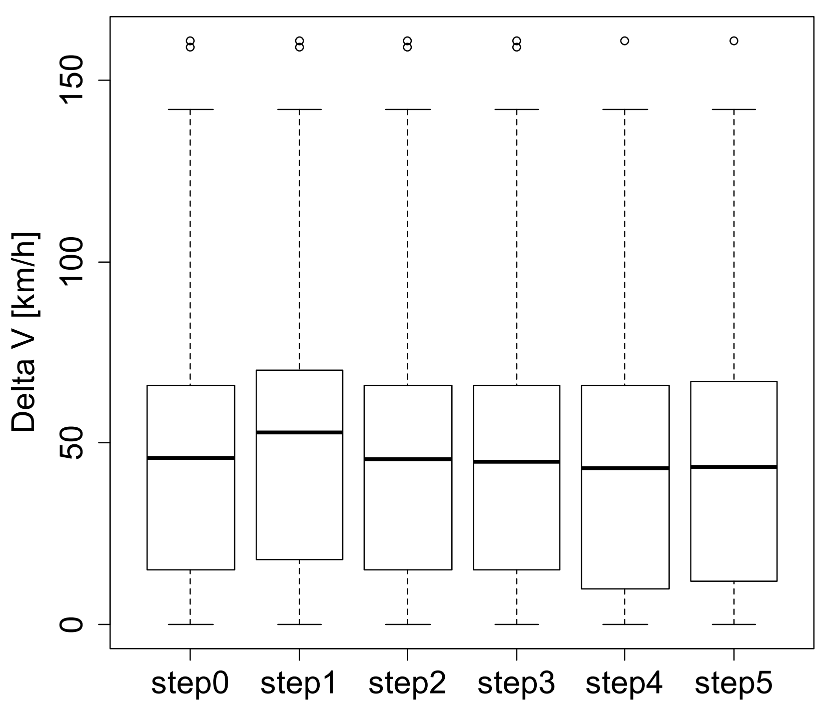


Fig. H7. DV all steps (conservative estimate).