Roads that Cars Can Read  REPORT III

Tackling the Transition to Automated Vehicles

EuroRAP  ROAD SAFETY  iRAP  Because every life counts.
Foreword by Ferry Smith, Chairman of EuroRAP

Much has been written about the safety benefits that autonomous vehicles should bring. But the ‘self-driving car’ will not solve all our road safety problems within the next couple of years. The challenge is much too big. The formal and informal communication between road users can’t be completely automated just yet. And, with a growing lifespan of vehicles, we will be confronted with older cars for decades. That’s the reality. Connectivity will also bring safety value to autonomous vehicles by making them cooperative, but again, all this will take time.

That doesn’t mean that nothing will happen in the meantime. Automation has found its way into modern vehicles already. Designed properly, they will continue to bring significant improvements in road safety.

Tens of millions of deaths and serious injuries have taken place on the world’s roads in recent decades: we have cruel statistical knowledge of how and where people are killed and maimed today. This paper takes our knowledge of these crash types and frequencies and considers how each might change as increasingly-automated vehicles enter the fleet. It paints a picture and provides a first estimate of how total serious trauma might reduce.

There are now internationally-agreed targets both for road safety and how to measure progress with safer road infrastructure, safer vehicles and safer behaviour on the roads. Recently, there has been much greater awareness of the role of safer road infrastructure. Even in the safest countries, the risk of death and serious injury on main roads can vary by 50 times or more. Typically, about half of all road deaths happen on main roads that form just 10% of the network.

Infrastructure ‘Star Ratings’ are today incorporated in the agreed global tracking framework. ‘Star Ratings’ and ‘Risk Mapping’ help civil society, elected representatives, authorities and researchers share a common language about how safe roads are – and how countries compare.

The long term goal is zero road deaths. Increasing vehicle safety will make a significant contribution but the transition to universal use of autonomous vehicles will, at best, take decades. Investment to make our infrastructure self-explaining and forgiving is needed not just to deliver roads that cars can read but to save lives by guiding all who use the roads.
Foreword by Erik Jonnaert, Secretary General ACEA

Improving road safety is a continuous effort that requires a contribution from each one of us. As policymakers prepare to set goals for 2030 and beyond that should be both challenging and realistic, this third paper in the series “Roads that Cars Can Read” helps us focus on how the total burden of fatalities and injuries could be reduced.

The automotive industry is deeply committed to the continuous improvement of road safety. Research and development programmes are bringing forward extraordinary advances in technology. Vehicles continue to become measurably safer year-on-year.

However, the improvement in vehicle safety must be matched by equal determination to improve infrastructure safety and traffic law. The regulation of both vehicles and roads must focus on bringing forward systems which reduce risks efficiently.

The advent of increasingly automated vehicles must not blind us to basic needs. Systems such as autonomous emergency braking will need robust road surfaces on which it is safe to ride, brake and corner. The laws of physics cannot be re-written. Roads will continue to carry vehicles of different types and weights as well as vulnerable road users. The need for safe lay-outs which protect all types of road users will remain.

This paper considers how different types of crashes might fall as vehicles with increasingly automated safety features enter the fleet. When making this analysis, we must also be conscious of where these crashes happen. It would seem that main single carriageways continue to present the greatest danger.

I believe this paper will help everyone working to assess investment in effective measures to improve road safety in Europe.
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About EuroRAP

The European Road Assessment Association (EuroRAP) was formed in 2002 as an international not-for-profit Association (AISBL) with support from the three top-performing governments in road safety (Netherlands, Sweden and the United Kingdom), together with the European Commission and civil society supporters from a dozen countries. EuroRAP today has around 60 authority or not-for-profit members from civil society, Ministries, authorities and research institutes in most European countries.

EuroRAP has supported more than 30 national road assessment projects and several large transnational projects within Europe, including the European Road Safety Atlas. The Association’s Members share unique databases on the comparative safety of Europe’s infrastructure safety and EuroRAP continues to support the European Commission in its development of road safety policy and the European Directive on Road Infrastructure Safety Management.

In 2005, EuroRAP helped lead collaboration developing a common global protocol for measuring the in-built safety of road infrastructure. It founded the award-winning International Road Assessment Programme (iRAP) to support the UN Decade of Action for Road Safety 2011-2020.

Today the principal role of EuroRAP is to enable high quality applications of the iRAP protocols in Europe. It helps develop “Safe System” research with the roads and motor industry and manages an accredited supplier network. It provides a forum for its Members to compare results and evaluate strategies and policies to save lives through safer roads.

EuroRAP protocols are embedded in national road safety strategies and guidance across Europe and, for example, used variously by the Police to target speed enforcement, guide speed limit-setting, as well as generating high value safer road investment programmes. Projects typically include professional training, together with major public communications. These results, data sets and software are available to the end-users, together with support in their use.

EuroRAP is a sister programme to Euro NCAP, the independent crash test programme that star rates new cars for the crash protection they provide to passengers and pedestrians. Euro NCAP demonstrates that well-designed crash protection can make family cars safer. Similarly, EuroRAP measures the safety performance of roads and demonstrates how and where they can be made safer.

EuroRAP is financially supported by its Members and the FIA Foundation, the European Automobile Manufacturers’ Association (ACEA) and iRAP.

About iRAP

The International Road Assessment Programme (iRAP) is a charity regulated to serve the public interest and dedicated to preventing the more than 3,500 road deaths that occur every day worldwide. At the heart of iRAP is a spirit of cooperation. The organisation provides tools and training to help mobility clubs, governments, funding agencies, research institutes and other non-government organisations make roads safer.

iRAP develops and maintains protocols to inspect high risk roads – Star Ratings, Safer
Roads Investment Plans and Risk Maps. It provides training, technology and support that builds and sustains national, regional and local capability. It helps to track global road safety performance so that funding and other agencies can assess the benefits of their investments.

The programme is the umbrella organisation for regional Road Assessment Programmes (RAPs), including AusRAP, BrazilRAP, ChinaRAP, EuroRAP, IndiaRAP, KiwiRAP, South AfricaRAP and usRAP. Programmes and projects have been undertaken in more than 85 countries throughout Africa, Asia Pacific, Central and South America, Europe, North America and the Middle East. More than 1,000,000km of roads have been risk mapped and more than 700,000km star rated.

iRAP is financially supported by the FIA Foundation for the Automobile and Society. Projects receive support from the Global Road Safety Facility, mobility clubs and associations, regional development banks and donors. National governments, mobility clubs and associations, charities, the motor industry and institutions such as the European Commission also support RAPs in the developed world and encourage the transfer of research and technology to iRAP. In addition, many individuals donate their time and expertise to support iRAP.

About the Road Safety Foundation

The Road Safety Foundation was established as a permanent legacy of the 1986 European Year of Road Safety. The charity has raised more than EUR 10m to fund its work, from insurers, philanthropy and other private and public sector support.

The charity was an early advocate of the Safe System approach, promoting road trauma reduction through simultaneous action on all three components of the safe road system: roads, vehicles and behaviour. Its behavioural work, particularly on young drivers and on supporting safe driving into old age, frequently guides government policies in the UK and elsewhere. It has researched the impact of air ambulance services and helped found both the European new car and road assessment programmes – Euro NCAP and EuroRAP. For more than a decade, the charity has been chaired by experienced Parliamentarians who have held road safety responsibilities at Ministerial level.

The charity has played a pivotal role in raising awareness and understanding of the importance of road infrastructure and proposing the strategies and goals that Governments can set in order to save tens of thousands of lives and disabling injuries. Most recently it has:

• undertaken strategic analysis for a dozen countries in south east Europe participating in the SENSOR project
• undertaken analysis to estimate the safety performance of Europe’s key trade routes (TEN-T)
• trained dozens of British local authorities in the use of iRAP protocols to target England’s 50 most dangerous roads and support evaluation of high return applications to the UK government’s innovative Safer Roads Fund

The charity has published annual safety ratings of British main roads for more than 15 years, allowing tracking of progress and recognition through annual Prince Michael Awards to authorities with the most improved roads.
Abstract

This paper examines the relationship between road infrastructure and safety for conventional and increasingly-autonomous vehicles (AVs) as the latter become more common on road networks. It builds on the theme “Roads that Cars Can Read” and the reports produced jointly in 2011 and 2013 by EuroRAP and Euro NCAP.

Much is known about the patterns of fatalities and severe injuries for crashes involving conventional vehicles. Gradual transition to AVs will introduce new collision partners as they collide with other road-users, with infrastructure and, potentially, with each other. Safe AV use will require that road infrastructure features are reliably detectable and that AV manoeuvres are accurately anticipated by other road-users.

Summaries are provided of current crash patterns and what countermeasures are required on today’s roads for conventional vehicles. Questions are asked about how these measures may change with the introduction of AVs. A timeline for possible crash changes from the initial integration of AVs is suggested and accompanying changes to infrastructure provision and maintenance are discussed. A scenario is presented showing that a reduction of about a quarter in severe crashes may be possible at the stage when a half of all travel on a national inter-urban network is in AVs. Future knowledge database requirements are noted. A proposal is presented to investigate what safety benefits AVs may bring.

Further information

“Roads that Cars Can Read: Report III – Tackling the Transition to Automated Vehicles”, June 2018

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Other reports in this series may be found at:


See also: www.eurorap.org, www.irap.org and www.roadsafetyfoundation.org
1. Transition to autonomous vehicles

The Johari Window¹ was popularised in recent times by Rumsfeld² as a framework for considering how to think about future challenges:

“There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don’t know. But there are also unknown unknowns. There are things we don’t know we don’t know.”

That application of the Johari Window involved planning during conflict and war, but the comments are relevant to some of the uncertainties involved in addressing the transition to autonomous vehicles (AVs).

The Society of Automobile Engineers³ divides AVs into six individual levels, from fully manual to fully automated:

• **Level 0 No Automation** – the human driver monitors and responds to the driving environment

• **Level 1 Driver Assistance** – the driver is supported by tools such as lane-keeping assist

• **Level 2 Partial Automation** – support such as cruise control and assisted steering with lane change assistance is provided

• **Level 3 Conditional Automation** – the vehicle can monitor its surroundings, change lanes, and can control the steering, power and braking in some situations. However, the driver must be ready to regain control of the vehicle when needed

• **Level 4 High Automation** – under the right conditions, the driver can switch the car to autonomous mode and not actively play any part in driving unless and until the vehicle comes across something that it cannot read or handle. It will then request help from the driver

• **Level 5 Full Automation** – cars at this level do not require a driver to be on board and are intended to do all the driving tasks under any conditions

Stradling⁴ commented in 2015 that a number of motor manufacturers had promised to have self-driving cars on sale by 2020, so that transition will begin soon. Litman⁵ noted that “new vehicle technologies generally require two to five decades from commercial availability to market saturation” and estimates that somewhere between 2040-2070 there may be a full fleet of fully-autonomous vehicles. Stradling has suggested that there may be a painful process to endure before the whole fleet


is autonomous and so, in his words: “That’s a lot of mixed-fleet running for us to negotiate in the meantime. There may be troubles on the road ahead.”. The question is: do we carry on as we are and deal with it when it arrives or do we take action now so that we can cope with what is coming?

EuroRAP and Euro NCAP have drawn attention to the problems for increasingly-autonomous vehicles of infrastructure deficiencies⁶. Austroads⁷ has made a very useful contribution to explaining the complexities for the road operator – for example, the inter-action of vehicles with land-use in streetscapes, how circumstances at some situations may need to be refined (complex intersections, pick up and drop off points, incident clearance) and how AVs would cope with special events such as roadworks. More recently, the European Commission has said⁸ that infrastructure deficiencies “…leads to the realisation that a true (ubiquitous) SAE level 5 vehicle may not be possible (as comprehensive infrastructure support will likely never cover the entire road network)”.

This paper is concerned with the relationship between road infrastructure and safety for both conventional and increasingly-autonomous vehicles as the latter become more common on road networks. Understanding the current situation and looking forward may relieve some of the anxieties described above. The paper provides a framework for considering these issues and works within the structure of the Johari Window (Table 1). Table 1 explains that the POV (Point of view) character potentially has a different set of information and knowledge at his/her fingertips from those of others observing the same situation. Recognition of where there are gaps may enable that knowledge to be built or to be anticipated.

Table 1 Who knows what in the transition to autonomous vehicles?

<table>
<thead>
<tr>
<th>Other characters’ view</th>
<th>Know</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Know</td>
<td>Known knowns: the things that the POV character and others know – for example, existing crash patterns</td>
<td>Known unknowns: the things that we know we don’t know – for example, future crash patterns</td>
</tr>
<tr>
<td>Don’t know</td>
<td>Unknown knowns: things others may know but that the POV character may not or may refuse to admit – for example, a sceptic’s view of the benefits to be gained from implementing crash countermeasures</td>
<td>Unknown unknowns: things that are true but no one (yet) knows</td>
</tr>
</tbody>
</table>

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The issues in Table 1 are multi-dimensional and Table 2 below hints at what some of the risk, trust, legal, insurance and social components of the change to AVs will be. Table 2 only scratches the surface – it does not consider what some of the problems may be, for example, of systems failures, hacking, terrorism or the issues of adoption that there may be in Low and Middle-Income countries.

This paper is mainly concerned with item 2 in Table 2 and with the infrastructure crash risk elements of this transition. It talks about existing and potential future crash patterns and touches on how current and conventional approaches to infrastructure safety may change.

Table 2 Transition to autonomous vehicles: “where we are now” and “where we want to get to”

<table>
<thead>
<tr>
<th>Where we are now</th>
<th>Where we want to get to</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What the likely rate of transition to AVs will be is little understood</td>
</tr>
<tr>
<td></td>
<td>Low, medium and high forecasts of the proportion and type of AVs over 40-80 years and the geographic and network coverage</td>
</tr>
<tr>
<td>2</td>
<td>Specific knowledge of how road risk will change with transition to AVs is patchy</td>
</tr>
<tr>
<td></td>
<td>Reliable risk patterns for vehicle occupants and vulnerable road-users, based on expected changes</td>
</tr>
<tr>
<td>3</td>
<td>Knowledge about vehicle, infrastructure and behavioural change is scarce and incomplete</td>
</tr>
<tr>
<td></td>
<td>A systematic framework establishing core data and multidisciplinary linkages between each</td>
</tr>
<tr>
<td>4</td>
<td>Suspicion and distrust exists among road-users about the effects of transition to change</td>
</tr>
<tr>
<td></td>
<td>Increased transparency and awareness of the transition by use of public and technical “road maps”</td>
</tr>
<tr>
<td>5</td>
<td>Knowledge about what the priorities and standards will need to be to reduce crash likelihood and severity for road-users is limited</td>
</tr>
<tr>
<td></td>
<td>An extensive road safety infrastructure database that will understand the risk and can rate future designs and layouts for safety of all road-users during mixed-fleet operating conditions</td>
</tr>
</tbody>
</table>

1.1. Two parallel transitions

Arguably, there are two simultaneous transitions taking place: one is the extent to which vehicles with at least some degree of autonomy are becoming part of the vehicle fleet (for example, Level 2 and above); the other is the proportion of driverless (Level 5) cars in the mix. Within this transition also lies the development of connected vehicles and the extent to which they can interact successfully with infrastructure, each other, with other vehicles and with vulnerable road users. The relationship between connectivity and autonomy is also relevant here. The discussion in this document targets the end-point of SAE Level 5 autonomy, but much of the discussion is also relevant to the automated processes that contribute to SAE Levels 1-4.
2. What are the “known knowns”?

“Known knowns” are what we know and understand. What is the current risk, for example, on urban roads? Using Britain as an example, four-fifths of all reported KSI (killed and seriously injured) casualties in urban areas are in crashes involving cars (Table 3a). The car-pedestrian KSI casualty is most common (29% of the urban sample assessed here). Car collision casualties with motorcycles (16%) rank ahead of bicycles (15%) and other cars (11%). Collisions involving other vehicles (eg trucks and buses) are less common.

Table 3a Crash partnerships and configurations (KSI casualties, 2015, Great Britain), Urban

<table>
<thead>
<tr>
<th>Crash partners</th>
<th>Conventional car</th>
<th>Roadside hazards</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Pedestrian</th>
<th>Other vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional car</td>
<td>11% (of total) KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt 1,276 KSI</td>
<td>6% KSI. Mainly: Run off or rollover SVNP* 691 KSI</td>
<td>16% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt 1,813 KSI</td>
<td>15% KSI. 2-vehicle. Mainly: cycling along, across road or at intersection 1,721 KSI</td>
<td>29% KSI. Walking along or across the road. 3,389 KSI</td>
<td>3% KSI. 393 KSI</td>
</tr>
<tr>
<td>Roadside hazards</td>
<td>4% KSI. SVNP. Mainly: Run-off or fall off. 448 KSI</td>
<td>1% KSI. SVNP. Mainly: Run-off or fall off. 143 KSI</td>
<td>N/A</td>
<td>N/A</td>
<td>2% KSI. 185 KSI</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>&lt;1% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt. 24 KSI</td>
<td>&lt;1% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt. 53 KSI</td>
<td>2% KSI. Along, Across. 206 KSI</td>
<td>2% KSI. 231 KSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>&lt;1% KSI. Mainly: Head-on Intersection, Shunt. 22 KSI</td>
<td>&lt;1% KSI. Mainly: Head-on Intersection, Shunt. 94 KSI</td>
<td>1% KSI. Along, Across. 94 KSI</td>
<td>3% KSI. 292 KSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5% KSI. 600 KSI</td>
<td></td>
</tr>
<tr>
<td>Infrastructure (Roadside hazards)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;1% KSI. 43 KSI</td>
<td></td>
</tr>
</tbody>
</table>


Notes to Table 3a: 11,624 KSI casualties involved in these scenarios from a 2015 total of 8,340 urban vehicle casualties and 4,524 pedestrian casualties = 90%. Table 3a excludes collisions with three or more vehicles; vehicle-vehicle collisions involve only 2 vehicles; casualties are all KSI involved. Includes casualties of all road-user types involved in the collision – eg in both vehicles; “Other vehicles” includes: bus, coach, van/light goods, heavy goods (truck), “Any other vehicle”; “SVNP” – single-vehicle non-pedestrian collisions; extensive under-reporting (ie 90+% of single-vehicle cyclist collisions). Darker shades of red represent greater casualty concentration. Shunt crashes involve a vehicle driving into the rear of the another, generally when the struck vehicle is slowing or stopped.
What is the current risk on rural roads? In Britain, the rural picture (including roads in villages) is very different from the urban. In rural areas, car crashes contribute about four-fifths of all rural KSI casualties, with single-vehicle non-pedestrian collisions (SVNP) being 28% of the total and car-car collisions 22%. Motorcycle-car collisions contribute 12% of KSI casualties (Table 3b). Later sections of this paper focus on crashes on the predominantly inter-urban British road network, arguably a less complex environment than the urban, to explore what benefits in severe crash reduction may be achieved.

Table 3b Crash partnerships and configurations (KSI casualties, 2015, Great Britain), Rural

<table>
<thead>
<tr>
<th>Collision partners</th>
<th>Conventional car</th>
<th>Roadside hazards</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Pedestrian</th>
<th>Other vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional car</td>
<td>22% of total KSI. 2-veh Mainly: Head-on, Intersection, Shunt. 2,260 KSI</td>
<td>28% KSI. SVNP Mainly: Run-off or rollover. 2,866 KSI</td>
<td>12% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt. 1,247 KSI</td>
<td>6% KSI. 2-vehicle. Mainly: running along, across road or at intersection. 796 KSI</td>
<td>5% KSI. Walking along or across the road. 557 KSI</td>
<td>8% KSI 796 KSI</td>
</tr>
<tr>
<td>Roadside hazards</td>
<td>8% KSI. SVNP. Mainly: Run-off or fall off. 828 KSI</td>
<td></td>
<td>2% KSI. SVNP. Mainly: Run-off or fall off. 177 KSI</td>
<td>N/A</td>
<td>2% KSI. 244 KSI</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt. 59 KSI</td>
<td></td>
<td>&lt;1% KSI. 2-vehicle. Mainly: Head-on, Intersection, Shunt. 17 KSI</td>
<td>&lt;1% KSI. Along, Across. 42 KSI</td>
<td>2% KSI. 209 KSI</td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td></td>
<td></td>
<td>&lt;1% KSI. Head-on, Intersection, Shunt. 17 KSI</td>
<td>&lt;1% KSI. Along, Across. 15 KSI</td>
<td>1% KSI. 141 KSI</td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>1% KSI. 117 KSI</td>
<td></td>
</tr>
<tr>
<td>Infrastructure (Roadside hazards)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1% KSI. 154 KSI</td>
<td></td>
</tr>
</tbody>
</table>

Notes to Table 3b: Definitions of Table 3a apply. 10373 KSI casualties involved in these scenarios from a 2015 total of 10816 rural vehicle casualties and 824 pedestrian casualties = 94%. Rural roads are those major roads and minor roads outside urban areas and include roads in settlements having a population of less than 10 thousand.
3. What are the “Known unknowns”? 

“Known unknowns” are the expected or foreseeable conditions which can be reasonably anticipated, but not quantified, based on past experience.

What will the new crash configurations be in the transition to AVs? Can it be anticipated that AVs will have similar crash configurations to conventional vehicles? If it can be, the introduction of AVs provides possibilities for additional collision partners, that is between AVs themselves and between AVs and other road-users (Table 4a, in red). AVs may protect themselves to some extent from these because they will be designed to act in the same way that human drivers do, but ideally more competently so that the current crash configurations of conventional vehicles are unchanged. AVs may also lose control and their occupants sustain injury in run-off or roll-over collisions although such crashes are unlikely to happen in the same proportions as the conventional crashes in Tables 3a and 3b. Other types of crash may also become priorities.

Note that Tables 4a and 4b assume a rather forced “black and white” distinction between conventional and autonomous cars. In reality, many of the advanced safety systems that will be standard on “conventional” vehicles are already changing the crash types involving the vehicles which have such systems. This is starting to be seen with autonomous emergency braking and the frequency of shunts. For the sake of simplicity in this discussion, Level 1-3 vehicles are considered as closer to conventional vehicles than fully autonomous and the crashes involving AVs that Table 4a presents are those that we might expect from existing knowledge of current crash patterns. The priorities for their treatment may actually differ from those of today and may vary according to the perspective of road and vehicle engineers.
### Table 4a Potential new crash configurations (in red) in the transition to autonomous vehicles

<table>
<thead>
<tr>
<th>Crash partners</th>
<th>Conventional car</th>
<th>Autonomous vehicle</th>
<th>Infrastructure (Roadside hazards)</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional car</td>
<td>Head-on Intersection Shunt</td>
<td>Head-on Intersection Shunt</td>
<td>Run-off or rollover</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across Intersection</td>
<td>Along Across</td>
</tr>
<tr>
<td>Autonomous vehicle</td>
<td>Head-on Intersection Shunt</td>
<td>Run-off or rollover</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across Intersection</td>
<td>Along Across</td>
<td></td>
</tr>
<tr>
<td>Infrastructure (Roadside hazards)</td>
<td>Run-off or fall off</td>
<td>Run-off or fall off</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Head-on Intersection Shunt</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.1 The knowledge base of collisions and countermeasures

iRAP work measures and manages the risk associated with different road infrastructure components, and in the process of making roads safer, estimating how that risk will change when different countermeasures are implemented. Countermeasures may be grouped into which of these crash components they will counter, with some treatments influencing more than one crash type.

How much do we know about the risk and the relevant countermeasures? For the existing mix of traffic, road design and road-users the knowledge base is strong for the most common crash types. Knowledge is strongest for collisions involving conventional cars. This is notably true for head-on and intersection collisions with other cars, for run-off crashes, crashes with motorcyclists at intersections and for those with pedestrians as they walk across the road. There is a vast research literature demonstrating the economic and social benefits of investing in crash countermeasures. Some motorcycle crashes are also well understood – run-offs and those with pedestrians. Other types of crashes have only a modest knowledge base associated with them.

---

Table 4b summarises current knowledge, based on the experience and opinion of the author and supported by the world literature on road engineering crash countermeasures, showing where knowledge is strong, moderate and weak. By comparison, and from the perspective of the road engineering role in crash occurrence and the understanding of the necessary countermeasures, the knowledge base to assess future risk involving AVs is weak. The vehicle industry has though been tracking the risk associated with increasing autonomy and in Appendix I there is a description of some of the earliest crashes involving AVs. Work by bodies such as Euro NCAP suggests that new crash types will emerge and that these will also become a priority for treatment.

### Table 4b Notional evidence base – risk or causation research and countermeasure effectiveness – strong, moderate and weak

<table>
<thead>
<tr>
<th>Crash partners</th>
<th>Conventional car</th>
<th>Autonomous vehicle</th>
<th>Infrastructure (Roadside hazards)</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional car</td>
<td>Head-on Intersection Shunt</td>
<td>Head-on Intersection Shunt – conventional into AV and vice versa</td>
<td>Run-off or rollover</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across Intersection</td>
<td>Along Across</td>
</tr>
<tr>
<td>Autonomous vehicle</td>
<td>Head-on Intersection Shunt</td>
<td>Run-off or rollover</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across Intersection</td>
<td>Along Across</td>
<td></td>
</tr>
<tr>
<td>Infrastructure (Roadside hazards)</td>
<td></td>
<td></td>
<td>Run-off or fall off</td>
<td>Run-off or fall off</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td></td>
<td>Head-on Intersection Shunt</td>
<td>Head-on Intersection Shunt</td>
<td>Along Across</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td></td>
<td></td>
<td>Head-on Intersection Shunt</td>
<td>Along Across</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some understanding of the distribution of these crash types on the motorway and A road inter-urban network in Britain can be gleaned from Table 5 below which divides the Road Safety Foundation EuroRAP network into “built-up” roads (through villages and small towns – speed limit ≤ 40 mph) and “non-built-up” roads (inter-urban of > 40 mph) (Appendix II). Table 5 provides pointers to where crash reductions on that network need to be found if AVs are to provide benefits, but how and where are
currently “known unknowns”. In Table 5, intersection crashes are the most common for KSI crashes, while run-offs are the single largest cause of deaths within the crash categories considered. Vulnerable road-user (VRU) deaths, mainly pedestrians, are more common on built-up roads. On non-built up roads the injury severity of pedestrian collisions is noticeably greater than on built up roads, probably due to higher speeds. To reduce casualties substantially, solutions must be found for crashes on single carriageways, notably at intersections. Not unexpectedly, head-on crashes are most common on single-carriageway roads. On motorways, shunt crashes, whilst not a large number overall, are responsible for more than a third of serious crashes.

### Table 5 Severe crashes by speed limit, road class, severity and crash type, inter-urban roads
**Great Britain 2013-15**

<table>
<thead>
<tr>
<th>Speed limit</th>
<th>Road classification</th>
<th>Severity</th>
<th>VRU</th>
<th>Intersection</th>
<th>Run-off</th>
<th>Head-on</th>
<th>Shunt</th>
<th>Other</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built up roads 40mph or less</td>
<td>Single 'A'**</td>
<td>Fatal</td>
<td>155</td>
<td>104</td>
<td>71</td>
<td>37</td>
<td>7</td>
<td>20</td>
<td>394</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>2,617</td>
<td>2,169</td>
<td>404</td>
<td>254</td>
<td>136</td>
<td>496</td>
<td>6,076</td>
</tr>
<tr>
<td></td>
<td>Dual 'A'</td>
<td>Fatal</td>
<td>15</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>206</td>
<td>269</td>
<td>34</td>
<td>8</td>
<td>42</td>
<td>61</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td>Motorway</td>
<td>Fatal</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Mixed 'A' (single and dual links)</td>
<td>Fatal</td>
<td>35</td>
<td>28</td>
<td>15</td>
<td>7</td>
<td>2</td>
<td>10</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>553</td>
<td>479</td>
<td>51</td>
<td>37</td>
<td>42</td>
<td>98</td>
<td>1,260</td>
</tr>
<tr>
<td>Total</td>
<td>Fatal</td>
<td>206</td>
<td>143</td>
<td>91</td>
<td>46</td>
<td>10</td>
<td>36</td>
<td>532</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td>3,379</td>
<td>2,922</td>
<td>491</td>
<td>299</td>
<td>224</td>
<td>1,657</td>
<td>7,972</td>
<td></td>
</tr>
<tr>
<td>Non-built up roads (inter-urban) Greater than 40mph</td>
<td>Single 'A'</td>
<td>Fatal</td>
<td>147</td>
<td>252</td>
<td>366</td>
<td>220</td>
<td>10</td>
<td>110</td>
<td>1,105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>675</td>
<td>2,180</td>
<td>1,569</td>
<td>913</td>
<td>258</td>
<td>813</td>
<td>6,408</td>
</tr>
<tr>
<td></td>
<td>Dual 'A'</td>
<td>Fatal</td>
<td>72</td>
<td>50</td>
<td>93</td>
<td>8</td>
<td>33</td>
<td>36</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>199</td>
<td>548</td>
<td>498</td>
<td>31</td>
<td>385</td>
<td>258</td>
<td>1,919</td>
</tr>
<tr>
<td></td>
<td>Motorway</td>
<td>Fatal</td>
<td>53</td>
<td>21</td>
<td>115</td>
<td>4</td>
<td>50</td>
<td>27</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>41</td>
<td>212</td>
<td>552</td>
<td>6</td>
<td>607</td>
<td>297</td>
<td>1,715</td>
</tr>
<tr>
<td></td>
<td>Mixed 'A' (single and dual links)</td>
<td>Fatal</td>
<td>62</td>
<td>52</td>
<td>70</td>
<td>51</td>
<td>15</td>
<td>38</td>
<td>288</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Serious</td>
<td>207</td>
<td>628</td>
<td>303</td>
<td>125</td>
<td>160</td>
<td>216</td>
<td>1,639</td>
</tr>
<tr>
<td>Total</td>
<td>Fatal</td>
<td>334</td>
<td>375</td>
<td>644</td>
<td>283</td>
<td>108</td>
<td>211</td>
<td>1,955</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Serious</td>
<td>1,122</td>
<td>3,568</td>
<td>2,922</td>
<td>1,075</td>
<td>1,410</td>
<td>1,584</td>
<td>11,681</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>Fatal</td>
<td>540</td>
<td>518</td>
<td>735</td>
<td>329</td>
<td>118</td>
<td>247</td>
<td>2,487</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>Serious</td>
<td>4,501</td>
<td>6,490</td>
<td>3,413</td>
<td>1,374</td>
<td>1,634</td>
<td>2,241</td>
<td>19,653</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>Fatal &amp; Serious</td>
<td>5,041</td>
<td>7,008</td>
<td>4,148</td>
<td>1,703</td>
<td>1,752</td>
<td>2,488</td>
<td>22,140</td>
<td></td>
</tr>
</tbody>
</table>

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*Based on the EuroRAP network and selected by polygon search
**A-class roads are second-tier major roads and outside built-up areas are of regional or more than local importance*
4. “Safe System” and supporting measures

Countermeasures can conveniently be categorised into those that are Safe System measures and those that are supporting treatments. The Australasian College of Road Safety has said\(^\text{12}\) that “…as a broad summary, Safe System countermeasures aim either to prevent a crash from occurring or to reduce the severity of that crash, while minimising the possible role of human error in precipitating the crash.” Those most apparent as Safe System measures include central and nearside barriers that prevent opposing vehicles striking each other head-on or striking roadside hazards; dedicated facilities for vulnerable road-users that provide separation are also in this group – for example cycle lanes. Some types of intersection design may also qualify – 3-leg intersections with protected turns, well-designed roundabouts where the entry deflection and approach angle is such that collisions are more likely to involve a glancing coming-together rather than a brutal right-angled side impact.

While signing and lining is often referred to as a supporting countermeasure, it is clearly going to be significantly more important in the transition period. Increasingly-autonomous vehicles rely very heavily on clear and visible lines and signs for lane-keeping, speed limit compliance and hazard warnings and will do so until or beyond a time when GPS or other technology provides complete support. High quality road signing and marking for cars that are developing towards autonomy has been highlighted by the EuroRAP-Euro NCAP reports\(^\text{13, 14}\) on Roads that cars can read and there have been other well-publicised reports of this need\(^\text{15}\). As an example, poor white line delineation increases risk by about 20% in conventional vehicle travel\(^\text{16}\). Given the dependency of increasingly-autonomous vehicles on sensors, arguably, improving the visibility of curves, intersections and pedestrian crossings provides particular benefits that helps conventional and AVs alike.

A 2017 consultation from the European Commission asked: “In your opinion, how ready is the existing road infrastructure for the deployment of automated or connected driving?” EuroRAP’s submission built on the findings of Roads that Cars Can Read and included the following\(^\text{17}\):


15The second recommending that lane and edge marking should be a consistent 150 millimetres wide and that these markings in the dry should reflect light at 150 milllicandela (formally 150 mcd/lux/m²)


18Submission from John Dawson on behalf of EuroRAP AISBL to the survey “Public consultation on infrastructure and tunnel safety”, European Commission, September 2017
“Basic road signs and markings are commonly not laid out in a way that is consistent and continuously clear to drivers. Equally, flawed signs and markings cannot commonly be interpreted reliably by vehicles, leading to dropouts, false readings or similar.

“People and highly automated vehicles can only 'read' road signs reliably where these are not worn out, obscured by vegetation or pointing in a direction where it is not clear to which lane they refer. In-vehicle equipment needs to understand a wide range of national implementations of even mandatory signs (such as ‘stop’ or ‘give way’) that are meant to comply with the Vienna convention. These vary in font, colour, size and shape. Sign plates qualifying signs in plain local language are a special challenge (eg No Right Turn ‘except...’)

“Road markings are frequently non-existent and obscured on main roads. In-vehicle equipment such as cameras can be confused by contrast from: old road markings; bitumen track that seals cabling or drainage; discontinuous lines; non-standard road markings; white lines in snow.

“Road edges which are marked may not be safe to travel on because of failed edges.

“A change in the approach to road maintenance is required so that the safety of the signing, marking and integrity of main roads is quality assured in a manner equivalent to air and rail transport. This is affordable, cost effective and imperative for the higher speed road networks of economic importance outside major urban areas where the majority of road deaths and the majority of travel is concentrated.”

AVs have been tested on roads for several years and some have been in crashes. Appendix I highlights some of them, providing a glimpse of what may be ahead. These incidents are of collisions with other traffic, presumably most in urban areas, with the AV generally not “at fault”. Those described have happened predominantly at either intersections or when free-flow is interrupted and a rear-end shunt is involved – commonly tackled today by improving road surfaces and signing or providing protected turns. A couple of crashes have involved a lane-changing manoeuvre. The sample described involves mainly low-energy impacts that have not involved injury. The picture that emerges is of a small number of AVs as the innocent party in the roadway although a report by the Virginia Tech Transportation Institute (in January 2016) says they are insufficient to draw solid conclusions.

AVs will bring improved lane-keeping, distance-keeping and autonomous emergency braking and can be required to comply with the posted speed limit with Intelligent Speed Adaptation. This may reduce their propensity to be involved in head-on and run-off crashes, and to be the striking vehicle in shunt crashes. At intersections, the awareness by an AV of the presence of other vehicles should reduce risk. The ability of AVs to recognise and avoid both each other and other road-users will be a key element in reducing conflicts. (It is assumed that motorcycles and bicycles are unlikely to become autonomous; they and a residual of other vehicles will remain under driver control.) Table 6 takes some of the crash partners introduced in Tables 1-5 and highlights some of the issues as risk changes.
### Table 6 Autonomous vehicles, crash configuration influencers and infrastructure attributes

<table>
<thead>
<tr>
<th>Crash partners</th>
<th>Potential changes in risk</th>
<th>Examples of infrastructure needed</th>
</tr>
</thead>
</table>
| **AV vs conventional vehicle** | *Head-on* – better lane-keeping  
**Intersection** – presence detection and road positioning enhanced; increased connectivity  
**Shunt** – distance-keeping and early autonomous emergency braking improved  
Lower likelihood of crash severity from speed control and speed limit compliance but may increase conventional vehicles striking autonomous cars | Signing and lining; median barriers  
Priority intersections or roundabouts or signals – which will be best for AVs?                                                                 |
| **AV vs AV**           | Similar to above but with risk reduced due to AV increased control and connectivity – eg shunt crashes eliminated                                                                                                      | Signing and lining; connectivity with roadside infrastructure and with vehicles                   |
| **AV vs infrastructure** | *AV* – better lane-keeping, speed adjustment on curve, barriers required but less often (speed reduction, reduced threat from roadside hazards), V-2-I connectivity with roadside and traffic information | Signing and lining – verge measures such as a revision of roadside crash restraint policy (ie provision of barriers). Connectivity |
| **AV vs motorcycle**   | Similar to AVs versus conventional vehicle but also dependent on ability of AV to detect motorcycle and of rider to interpret manoeuvres of car and vice versa                                                                 | Signing and lining, median barriers; which is best for road-users; priority vs roundabouts vs signals?  
Motorcycle recognition by other vehicles and infrastructure                                                                 |
| **AV vs bicycle**      | Similar to AV versus conventional vehicle but also dependent on ability of AV to detect bicycle and of rider to interpret manoeuvres of car and vice versa                                                                 | Signing and lining; median barriers, nearside segregation, priority vs roundabouts vs signals; bicycle recognition as above |
| **AV vs pedestrian**   | Ability of AV to detect pedestrian and of pedestrian to interpret manoeuvres of car and vice versa                                                                                                                      | Pedestrian recognition as above; nearside segregation; crossing designs and priority               |

Choice of appropriate intersection control and the ability of all vehicles to cope and pass safely will be critical, as indeed will AV-pedestrian interaction. The components of AV and driver interaction raise important questions. Taking only five examples, consider how risk at these locations might change or how vehicles may need to switch from autonomous to manual mode:

- An AV emerging from a minor road, turning left (using a drive-on-the-right convention) across a busy traffic stream of conventional vehicles would be unable to rely upon the eye contact that may often be a means of gaining permission to enter the intersection.

- A wary motorcyclist on the main road often depends upon this same eye contact when looking for reassurance that they have been detected and seen by the emerging vehicle driver. How does the absence of that contact influence risk and behaviour?

- An AV, programmed to be cautious, slowing down at a roundabout or give-way priority intersection may stop, whereas a driver of a following conventional vehicle may believe entry is safely possible and speed up, thereby risking a rear end shunt.
On roads where maintenance is low quality, it may not be clear that a pedestrian is actually on a crossing facility and therefore have priority over vehicles. This priority may not be observed or be recognised by an AV. Of 4,869 crossings surveyed in 14 countries in south-east Europe, 2,151 (44%) were described as poor quality (and often inconspicuous – see Figure 1), either because of a lack of signing and marking or poor maintenance. Will AVs be able to distinguish between pedestrians simply pausing or standing near a pedestrian crossing and those wishing to cross? The AV actually needs to detect whether there is a pedestrian crossing the road, irrespective of whether there is a pedestrian facility.

AVs may adopt conservative decision-making that can create delays and safety issues for following vehicles. The actions of AVs to avoid birds, other small animals or indeed large plastic bags, are also noted as an issue that may impact on following conventional vehicles.

Figure 1  Pedestrian crossings difficult to detect

Maintenance of infrastructure will be a key factor in the AV transition phase and maintenance will become a road authority higher-priority obligation. “Convergence of quality” such as consistency of white lining will be necessary and definition of minimum quality requirements will be a part of that. Currently driver behaviour and inattention are the most significant contributory factors in conventional vehicle crashes and that will diminish with autonomous vehicles. On the other hand, given the vast range in road quality, infrastructure is likely to play a greater proportional role in future crashes while AV technology failure may also result in more crashes. It is a generally-held view that driver liability will decrease while road authority and manufacturer liability will increase.

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19Sabey B and Taylor H (1980) The known risks we run: the highway. TRRL Supplementary Report 567, Crowthorne Berkshire ISSN 0305-1315

5. Will crashes and countermeasures change?

What is the likely effect on recommendations for future countermeasures as AVs are introduced?

The unanimous view of the iRAP Innovation Workshop, convened to discuss this and other topics21, was that there is no early prospect of “cashing in” savings in infrastructure safety provision. There will be mixed fleets on most roads for decades and the roads need to be serviceable (for braking, cornering and ride), they will continue to require signs, markings and safe recovery zones together with Safe System defences such as safety barriers and roadsides free of rigid hazards.

For as long as conventional vehicles remain on the road, it is reasonable to argue that both the Safe System and supporting measures will be required. In Appendix III there is an example from the Netherlands of one of a series of iRAP surveys that highlights some countermeasures that will continue to be required for many years during the transition from conventional to AVs. They include:

- Run-off crash protection (eg barrier or clearzone)
- Loss of control mitigation (eg shoulder sealing, lane widening)
- Head-on crash protection or avoidance (eg barrier or 2+1 with barrier separation)
- Intersection upgrading (principally protected turns)
- Pedestrian provision along (footpath)
- Pedestrian provision across (crossing)
- Bicyclist provision (either on-road or off-road)
- Mixed combination (eg surfacing improvement with other measures)

The time horizon suggested in Appendix III for the investment in the Dutch roads is 20 years. How would these countermeasures be influenced by the introduction of AVs during this period? Would crashes involving AVs be reduced by any of these measures? Would conventional vehicles continue to benefit to the same extent?

Crashes involving conventional vehicles will certainly continue, although probably to a lesser extent as their proportion in the fleet diminishes. Good surfacing, signing and lining will be required, as will segregation or other protection of vulnerable road-users. Measures that mitigate loss of control that are good for conventional vehicles will presumably be good for AVs too.

During and after the transition:

- Barriers will be required as a failsafe for all vehicles on higher speed roads, autonomous or not, but justifying the simple economics of providing them will arguably become more difficult as crashes with these systems become less common

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• Countermeasures for crashes involving conventional vehicles, but also benefitting other road-users, may also become more difficult to justify economically unless they also benefit AVs – for example, street lighting or anti-skid surfacing.

• Some countermeasures currently popular because of the protection they provide to car occupants (for example, roundabouts), may become less necessary, thereby removing the heightened risk that some intersections provide, for example, to cyclists.

• As noted, places where pedestrians or other road-users have precedence must be conspicuous and understood by AVs.

• Some measures that currently counter “high frequency, high severity” events will gradually be catering for “lower frequency, high severity” events – collisions with roadside hazards and head-on collisions may be included in this category.

Drawing on some of Litman’s ideas, although noting the European Commission’s reservations about full autonomy, there will be a gradual increase of AVs into the fleet and the market will mature. Figure 2 places some of the issues discussed against a possible timescale and in an unspecified geographical area or region as AVs enter the fleet after 2020, with potentially more complex crashes gradually becoming less common over time. Motorway travel and travel in High Income countries may be the first to show benefits, with relatively minor roads in Low and Middle-Income countries last.

Figure 2 Notional timescales and crash changes in integration of autonomous vehicles
Crash data such as those in Tables 3a, 3b and 5 provide a base if assumptions are made about what the safety benefits of the AV may be. Road injury reduction projections are of course notoriously difficult and likely to be inaccurate. It is easy to overstate the possibilities. Nevertheless, if it is assumed that half of travel in about 30-40 years from now will be in AVs, then it is possible to view some potential scenarios for crashes involving these vehicles at that stage, with even more savings at market penetration beyond that. Better and more sophisticatedly-modelled estimates will become available over time. Here, example scenarios illustrate what the effects may be on overall numbers:

- Run-off crashes may be the easiest to counter – good signing and lining and in-vehicle lane-keeping support and speed control may reduce these crashes, especially on bends, by 60-80%

- Rear-end shunt crashes may be reduced by 60-80% with distance-keeping devices in vehicles

- Head-on crashes may be reduced by 40-60% – overtaking “head-on” probably by more than “loss of control head-on” (see Figure A6)

- VRU crashes may reduce by about 20-40%, assuming that pedestrians and cyclists benefit from AVs and that motorcyclists are relatively unaffected

- Intersections may only achieve a 20-40% reduction because they are more complex, although some intersection designs are likely to provide higher reductions than others

- Similarly, the myriad of crashes captured in “Other” may also be reduced by 20-40%

Taking these factors into account, a reduction by about a quarter of all crashes by around 2050-60 is offered as a starting point in this discussion (Table 7) subject to these assumptions:

- Other risk consequences of the interaction between autonomous and other vehicles are ignored (eg new risks introduced by mixed human- and autonomous-operated traffic)

- The characteristics and demographics of those adopting this transport do not substantially influence known crash patterns

- The introduction of AVs not having unintended and undesirable consequences

- And the reduction in crashes is assumed to apply at the high end of each of the above ranges

This quarter reduction in crashes approximates to about 1% per year if the reduction applies at a uniform rate, but inevitably that is unlikely since an increasing number of AVs will presumably have an influence on safety that varies year-by-year, less in the early years and more as 2050-60 is approached.
### Table 7 Reduction in severe crashes on inter-urban roads Great Britain comparing 2013-15 (see Table 5) with 50% travel by autonomous vehicles and assumptions as listed

<table>
<thead>
<tr>
<th>VRU</th>
<th>Intersection</th>
<th>Run-off</th>
<th>Head-on</th>
<th>Shunt</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,041</td>
<td>7,008</td>
<td>4,148</td>
<td>1,703</td>
<td>1,752</td>
<td>2,488</td>
<td>22,140</td>
</tr>
<tr>
<td>Influence of travel by AVs on crash reduction</td>
<td>40%</td>
<td>40%</td>
<td>80%</td>
<td>60%</td>
<td>80%</td>
<td>40%</td>
</tr>
<tr>
<td>4,033</td>
<td>5,606</td>
<td>2,489</td>
<td>1,192</td>
<td>1,051</td>
<td>1,990</td>
<td>16,361</td>
</tr>
<tr>
<td>Reduction, assuming an estimate at the high end of the range</td>
<td>1,008</td>
<td>1,402</td>
<td>1,659</td>
<td>511</td>
<td>701</td>
<td>498</td>
</tr>
<tr>
<td>Percentage reduction in overall crashes assuming an estimate at the high end of the range</td>
<td>20%</td>
<td>20%</td>
<td>40%</td>
<td>30%</td>
<td>40%</td>
<td>20%</td>
</tr>
</tbody>
</table>

The risk reductions described here are assumed to apply when half of all travel is by AVs. This may understate the potential influence of AVs in the mix – they may be likely, for example, to have the effect of slowing down conventional traffic, with a corresponding reduction in severe crash injury risk. But there are also arguments to suggest that impatient drivers in conventional vehicles may increase head-on risk due to injudicious overtaking.

Litman on the other hand has argued against a simple approach, suggesting that new risks will be created such as hardware and software failures, hacking, offsetting/risk compensation behaviour (the tendency of travellers to take additional risks when they feel safer), and crash risk dangers of platooning. He also suggests that AVs will encourage more travel in the absence of road pricing and encourage sprawling development and will impact on public transport, generating more traffic (See Appendix IV).

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Litman T (2017a) personal communication
6. What are the “Unknown unknowns” and “unknown knowns”?

Unknown unknowns are the unexpected or unforeseeable conditions which pose a potentially greater risk simply because they cannot be calculated from past experience or investigation. Returning to Table 1 (Who knows what in the transition to AVs), overlaid on this will be the “unknown unknowns” that will change what we expect to encounter. By definition, we don’t know what the unknown unknowns will be. We might though take a reasonable guess at what some of them will be and move them into the category of known unknowns. For example, anticipated new risks and the new crash countermeasures not yet developed that will be needed in the future – where and how the road will engage with the car through technology. Much of that is already emerging and becoming available.

Finally, “unknown knowns” are the fourth and remaining element of the matrix in Table 1. They escaped the attention of Rumsfeld but may include the practices that people intentionally refuse to acknowledge that they know about, even though they form the background of their values. This may, for example, be policy blindspots – information that we know about, but do not use, about how to reduce road deaths. The infrastructure will in the future, as now, demonstrate that there are crash-reducing countermeasure solutions that make sound economic sense to invest in but which we implicitly choose not to act upon, possibly for reasons of political or public acceptability. McInerney captured this in his address during the 2017 UN Global Road Safety Week. As we move into the transition period, the crash configurations in Tables 3a and 3b will continue to exist but they will be joined by the newcomers in Table 4a and action will be taken to build the knowledge and act upon the gaps explained in Table 4b. As McInerney notes within the context of a call for speed reduction and halving road deaths:

“...we must slow down and think whether we are truly doing enough to address this global killer. As politicians, as public servants, as business owners, as workers, as charities, as individuals. Are we doing enough different to challenge the status quo?”

Within the context of a call for speed reduction and halving road deaths he questions that commitment:

“How much are we investing to halve this problem? In most countries, we see targeted investment to save lives that equates to only $1-3 for every $100 of crash costs.”

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7. Where do we go from here?

7.1 Knowledge-building alongside invigorated existing practices

First and foremost, there is a need to carry out extensive surveys of the type described in the EuroRAP-Euro NCAP reports on Roads that Cars Can Read that will set benchmarks for the adequacy of existing road markings and traffic signing on the road networks. They will assess the deficiencies and direct what must be done to optimise that.

There is patchy knowledge of how road risk will change with the transition to AVs (item 2 in Table 2) and current knowledge of risk and countermeasure treatment is limited in some areas (Table 4b). Many current types have a weak or only moderate knowledge base so understanding more about those collisions and about the crashes that include AVs will be a priority. A process of knowledge-building about what the vehicle, infrastructure and behavioural change will be to establish a systematic framework between them is required (item 3 in Table 2).

It must include:

- Behavioural studies to monitor the interactions of conventional and AVs
- Conflict and near-miss studies involving AVs
- Detailed crash investigation
- Detailed analysis of AV data to understand collisions avoided, near misses and crash analysis
- Monitoring the effectiveness of crash countermeasures
- Assessment of how an increasing proportion of AVs in the fleet changes crash patterns and the countermeasures needed

Preliminary data from crashes involving AVs suggests that there is work to be done so that other road-users understand and learn to predict the manoeuvres of AVs, particularly at intersections.

The obligation on road authorities to maintain to common standards will increase during the transition. Several elements of infrastructure are and will be crucial to safety during the transition to AVs – they include support for lane-keeping and measures to avoid head-on and run-off collisions. As it is today, means of ensuring future speed limit compliance will be fundamental to safety. In many places the quality of the road system is not in a fit state to support AVs – for example, worn road markings, obscured and fading signs, poor edge delineation, worn out road surfaces.

We must continue to build the momentum required to implement the crash countermeasures needed to reduce the injuries associated with conventional vehicles. The transition to AVs should not distract from this task but at the same time we must monitor closely what action will be required to counter the new risks that are introduced.
7.2 Assessing the safety of a future with autonomous vehicles

The likely future contribution of AVs to safety could be assessed in the way that the influence of other safety technologies has been assessed in the past 25,26,27,28 by the detailed retrospective analysis of fatal crashes and assessment of how changes in vehicle design and road countermeasures could influence crash outcome. This would assess how existing collision types might be affected, but there is of course great uncertainty over which new types of crash might occur and increase during the transition. A study of existing crash types might take the following steps:

- Take a reasonable sized sample of fatal crash records. (Ideally, use files such as those generated for HM Coroner’s inquests (in England and Wales) that have scene plans, photos and witness statements including those of an expert witness.)

- Select fatal crashes involving the latest technology 5-star Euro NCAP vehicles, and analyse them for the possible influence of AVs in differing degrees of a mixed fleet 29

- Each crash would be analysed and understood by the research team and then considered from the perspective of one, two or all vehicles being autonomous

- With a clear definition at the outset of the assumed capabilities of an AV in terms of a comparison with a human driver, case-by-case a picture could be built up of the likely influence of varying degrees of AV fleet

- The analysis would be used to direct priorities for road improvements and used to highlight those areas that vehicle manufacturers and Euro NCAP could usefully focus on to improve further the protection for occupants and other road-users

This would be a relatively quick and defensible way of gaining insights into the future, without waiting the necessarily long period for the actual picture to emerge. Having taken the time to understand a given crash in sufficient detail to allow the assessment of the influence of AVs and their interaction with road infrastructure, the amount of additional effort to answer questions benefitting vehicle design (and, for example, testing by Euro NCAP) would be relatively small, making the joint analysis much more efficient than separate analyses. With or without a specific study, it would be useful for HM Coroners to be asked to provide certain information routinely in crashes involving an AV so that it is reported as a pro forma. Expert opinion could then be provided on the necessary steps required to avoid future deaths.

26Gloyns PF and Rattenbury SJ (1989) Cars in conflict with larger vehicles – the problem of under-run, SP782 SAE, Society of Automotive Engineers
29By analysing a group of fatal crashes involving 5-star vehicles, the autonomous vehicle analysis would be as “pure” as possible, showing the influence of AV in vehicles with relatively sophisticated occupant and pedestrian design.
7.3 Infrastructure Star Ratings for the self-driving car

As the evidence base grows for driver assistance technologies and AVs, the need for infrastructure Star Ratings specifically for the self-driving car can be explored. For example:

- A road with excellent all-weather line marking may reduce the run-off risk to almost zero because there would be few foreseeable conditions under which an AV would not be kept on the road. The high quality line marking coupled with the lane-keeping attributes of the vehicle may mean that it would contribute to a 4-star rating for an AV. That same road may only rate 2-star for a conventional vehicle.

- A signalised intersection may be safer for an AV than a roundabout because it provides for more predictable elements of the stop-start manoeuvre and gives more closely-defined turning manoeuvres

Other parameters will become relevant in this debate. By including consideration of the fleet penetration over time, optimum investment priorities for road users that will maximise lives saved per unit of investment can be established. Here again, spending patterns may change – for example, the Benefit Cost Ratio of renewing line marking may increase significantly.

8 Conclusions

This paper provides a framework for considering what the infrastructure safety investment issues in the transition to AVs may involve.

Taking Britain as an example, in urban areas the most common severe crashes currently involve cars colliding with pedestrians, followed by motorcycles, bicycles and then other cars. In rural areas, car collisions with roadside objects dominate, followed by cars colliding with cars, and to a lesser extent motorcycles – car collisions with bicycles and pedestrians are much less common on rural roads.

Transition to AVs will involve new collision partners as these vehicles collide with other road users and potentially with other AVs. There is good knowledge about many of the crash types that happen on today’s roads, but very little understanding of what may be anticipated in the frequency and the crash configurations involving AVs.

Some current crash countermeasures may be needed less than they are now in the future. Proving their economic benefits may become more difficult as a result. For example: barriers may be required less; the economic benefits of roundabouts over signal-controlled crossroads may be diminished.
A simple prediction of what benefits there may be when half of the vehicles on the road are autonomous suggests that a reduction of about a quarter of all fatal and serious crashes on inter-urban roads by around 2050-60 may be achieved – a reduction of about 1% per year on average, less in the early years and more as 2050-60 is approached.

In the transition to AVs, and probably beyond that period, good and consistent signing and lining will be required – AVs at various stages of transition, and drivers of vehicles without an autonomous function, will continue to rely on them.

There is a need to keep conventional crash countermeasures during the transition and they will continue to achieve good cost-benefits.

The transition to AVs should be prepared and planned for now, but should not be a distraction from the life-saving work that can be done using conventional approaches to crash reduction.

**Acknowledgments**

This paper was stimulated by ideas generated during a submission to the Horizon 2020 programme in January 2016 (Table 2), from a Loughborough University workshop on autonomous vehicles in February 2016 and from discussions with Steve Stradling in June 2017 and at the iRAP Innovation Workshop in the Netherlands in November 2017 (see “iRAP Innovation Workshop, 2017, Tackling the transition to highly automated vehicles – the assessment of road and vehicle investment priorities” at https://www.irap.org/2017/12/event-snapshot-innovation-2017/.) Cover artwork and Figure A6 by James Bradford, who, with Rob McInerney, Gareth Coles, John Dawson, Olivera Djordjevic, Peter Gloyns, Martin Howell, Risto Kulmala, Todd Litman, Julie Maes, Andrew Miller, Blair Turner and Michiel van Ratingen made useful contributions to discussion. Permission has been sought and granted for use of photos in Appendix I. Bert Morris provided editorial support. Designed by Black Sheep Create. Jo Hammond (TRL) provided data for Table 5. An earlier version of this paper was presented at the Transportation Research Board Annual Meeting 2018: https://trid.trb.org/view/1496103.
Appendix I

What is the recent history crashes involving self-driving cars?

Some recent crash histories gleaned from the internet paint a picture of generally low-energy impacts in urban areas, this of course determined by the location of the trials and the speeds at which the vehicles are operated.

Uber – crash and partial roll

Friday 24 March 2017:

“A spokesperson for the police in Tempe, Arizona, said the crash happened when another car “failed to yield” to an Uber car at a left turn. Josie Montenegro said: “There was a person behind the wheel. It is uncertain at this time if they were controlling the vehicle at the time of the collision.”

Figure A1 Uber side impact crash and partial roll

More recently (on 20 March 2018), an Uber vehicle has been involved in a fatal crash with a pedestrian pushing a bicycle across a 4-lane road – see [http://www.bbc.co.uk/news/business-43459156](http://www.bbc.co.uk/news/business-43459156).
Google

There are various reports of an early Google AV crash:\n
“In an accident report filed with the California DMV on February 23 [2016] (and made public today [29 February]), Google wrote that its autonomous car, a Lexus SUV, was driving itself down El Camino Real in Mountain View. It moved to the far right lane to make a right turn onto Castro Street, but stopped when it detected sand bags sitting around a storm drain and blocking its path. It was the move to get around the sand bags that caused the trouble, according to the report:

“After a few cars had passed, the Google AV began to proceed back into the center of the lane to pass the sand bags. A public transit bus was approaching from behind. The Google AV test driver saw the bus approaching in the left side mirror but believed the bus would stop or slow to allow the Google AV to continue. Approximately three seconds later, as the Google AV was re-entering the center of the lane it made contact with the side of the bus.”

Google’s car was in autonomous mode and driving at 2 mph at the time of the crash. The bus was driving at about 15 mph, per the report. No injuries were reported, but the front left wheel and fender of Google’s car were damaged.”

Virginia Tech Transportation Institute (January 2016) has published a study funded by Google of Self-Driving Cars (that included 11 crashes assessed whilst in autonomous mode) during a period May 2010-August 2015:

The collisions (see Table 5, pages 10-12 of that report) were all relatively low energy impacts, only two requiring occupants (of conventional vehicles involved in the collisions) to be assessed and released by hospital:

• 6 involved an AV being temporarily held up by other traffic and struck in the rear

In the others:

• The AV was sideswiped same-direction collision by a vehicle changing lane

• The AV was going straight ahead into intersection and was struck by vehicle also turning into intersection

• The AV was turning right into intersection and was struck in the rear

• The AV was decelerating in a traffic lane and received a same-direction sideswipe from another vehicle

• The AV was changing lanes and was struck in the rear by the other vehicle making a lane change

31 https://www.wired.com/2016/02/googles-self-driving-car-may-caused-first-crash/
The report extrapolates, makes extensive comparisons with crash data and summarises:

“When compared to national crash rate estimates that control for unreported crashes (4.2 per million miles), the crash rates for the Self-Driving Car operating in autonomous mode when adjusted for crash severity (3.2 million miles; Level 1 and Level 2 crashes [the more severe of those assessed but still predominantly damage-only]) are lower.”

“Additionally, the observed crash rates in the SHRP 2 NDS [Second Strategic Highway Research Program Naturalistic Driving Study] at all levels of severity were higher than the Self-Driving Car rates.”

“As Self-Driving cars continue to be tested and increase their exposure, the uncertainty in their event rates will decrease. Current data suggest that Self-Driving cars may have low rates of more-severe crashes (Level 1 and Level 2 crashes) when compared to national rates or to rates from naturalistic data sets, but there is currently too much uncertainty in in Self-Driving rates to draw this conclusion with confidence.”

Outside the study period of that report:

“A Google driverless car has collided with a commercial van, in what is thought to be the worst accident involving an autonomous vehicle yet. On Friday [16 September 2016], a Lexus outfitted with Google’s autonomous driving technology was struck by a van that ran a red light in Mountain View, California. A photo of the aftermath shows the car with a huge dent on the passenger side, and a van with a bashed-in bonnet being pulled onto a tow truck.”

Figure A2 Google side impact with van

Photo reproduced from the Daily Mirror news item.
According to a statement from Google\textsuperscript{33}, the traffic light

“…was green for at least six seconds before our car entered the intersection”. The crash happened at the corner of W El Camino Real and Calderon Ave. No one was hurt in the crash and all airbags deployed. “I only saw the tail-end of the crash, and the dazed Google employees sitting around afterwards waiting for their tow-truck,” a witness told 9to5Google. “From what I could see, it was the van’s fault entirely. This is not the first time a Google self-driving car has been involved in an accident. “Earlier this year, an autonomous Lexus collided with a bus while travelling at just 2mph. The car pulled out in front of the bus to avoid some sandbags in the road. The bus was only travelling at 15mph but the impact of the crash tore off the Lexus’ side radar and crumpled the left side of the bonnet.”

Figure A3 Google intersection crash – minor damage

University of Michigan (October 2015)

Three months prior to the Virginia Tech report Schoettle and Sivak (2015) published \textit{A preliminary analysis of real-world crashes involving self-driving vehicles}\textsuperscript{34} involving Google, Delphi and Audi AVs. The study assesses 11 crashes occurring between January 2012 and September 2015. Most, if not all, of the crashes in this study will have been included in Google’s own study. Their report comments that the mileage accumulated by the self-driving vehicles is low and that it was done in generally undemanding conditions. Schoettle and Sivak say the relative crash rate between autonomous and conventional vehicles is not completely clear (their sample and methodology differs from Virginia Tech’s), that self-driving vehicles were not at fault in the crashes assessed and that the relative severity of crashes in self-driving vehicles is lower than for conventional vehicles. See also the work of Teoh and Kidd\textsuperscript{35} in testing in comparing AV and conventional safety.

\textsuperscript{33}\url{http://www.mirror.co.uk/tech/google-driverless-car-involved-worst-8917388}
\textsuperscript{34}\url{http://umich.edu/~umtriswt/PDF/UMTRI-2015-34.pdf}
**Tesla fatality whilst running in “Autopilot” mode**

Not to be confused with cars operating in an autonomous mode, there has been much publicity in recent years over the fatality whilst a Tesla was operating in “Autopilot” mode:

“On May 7, 2016, a 2015 Tesla Model S collided with a tractor trailer crossing an uncontrolled intersection on a highway west of Williston, Florida, resulting in fatal injuries to the Tesla driver. Data obtained from the Model S indicated that: 1) the Tesla was being operated in Autopilot mode at the time of the collision; 2) the Automatic Emergency Braking (AEB) system did not provide any warning or automated braking for the collision event; and 3) the driver took no braking, steering or other actions to avoid the collision.”

**Figure A4 Tesla – under-run of a truck**

The crash was investigated in detail by the National Highway Traffic Safety Administration (2016):

“ODI [Office of Defects Investigation] analyzed mileage and airbag deployment data supplied by Tesla for all MY 2014 through 2016 Model S and 2016 Model X vehicles equipped with the Autopilot Technology Package, either installed in the vehicle when sold or through an OTA (over-the-air) update, to calculate crash rates by miles travelled prior to and after Autopilot installation.”

As a means of comparing risk rates, the Office of Defects Investigation calculated airbag deployment crashes in the subject Tesla vehicles before and after Autosteer installation. The data show that the Tesla vehicles’ crash rate dropped by almost 40 percent after Autosteer installation, from 1.3 to 0.8 crashes per million miles.

Appendix II

Figure A7 - The Motorway and A-road network described in Table 5 (source: Road Safety Foundation)
Appendix III

What is the possible effect on recommendations for future countermeasures as AVs are introduced? Consider an example from the Netherlands. As one of a series of iRAP surveys, 7,322km of carriageway of the Dutch provincial roads were surveyed by EuroRAP in 2014. This is a predominantly (92%) single-carriageway inter-urban network with generally very good provision for pedestrians and cyclists. 36% of the network scores 3-star or better on the iRAP rating for vehicle occupant safety. 94% of the network is classified as rural, with the remaining 6% passing through villages or small towns.

The iRAP surveys assess 52 attributes that are related to crash likelihood or severity every 100m and use detailed algorithms to assess which combinations of more than 90 countermeasures may reduce risk on each 100m.

A snapshot of some of the network Safe System deficits on the Dutch provincial roads is provided below in Figure A5. The iRAP tool models the crash initialisation scenarios shown in Figure A6 and the suggested countermeasures are provided in Table T1 in aggregated format. It can be seen in Figure A5 that the principal deficits relate to run-off, to head-on crashes and to intersections. Table T1 proposes a spending package and outlines the benefits in casualty reduction that may be achieved.

Figure A5 - Network deficits indicated by road attribute data – Dutch Provincial Roads

17% of roads where pedestrians are present and traffic flows at 40km/h or more have no footpath

18% of roads where bicyclists are present and traffic flows at 40km/h or more have no bicycle facilities

0% There are no sections of road with high motorcycle flows (>=20% of total) and traffic flows at 60km/h or more

84% of roads carrying traffic at 80km/h or more are undivided single carriageways

96% of curves where traffic flows at 80km/h or more have hazardous roadsides

69% of intersections where traffic flows at 60km/h or more have no roundabout, protected turn lane or interchange

**Figure A6 Crash initialisation scenarios modelled by iRAP**

<table>
<thead>
<tr>
<th>Initialisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Vehicle loss of control</td>
</tr>
<tr>
<td>2 Vehicle overtaking</td>
</tr>
<tr>
<td>3 Vehicle turning manoeuvre</td>
</tr>
<tr>
<td>4 Motorcycle travelling along</td>
</tr>
<tr>
<td>5 Pedestrian walking along road</td>
</tr>
<tr>
<td>6 Pedestrian crossing the road</td>
</tr>
<tr>
<td>7 Bicycle travelling along the road</td>
</tr>
</tbody>
</table>

**Table T1 Countermeasure proposals: costs and benefits (Dutch Provincial network over 20 years)**

<table>
<thead>
<tr>
<th>Principal objective of countermeasure</th>
<th>Length/ Sites</th>
<th>FSIs saved 20 yrs</th>
<th>PV (EUR) of safety benefit</th>
<th>Estimated Cost (EUR)</th>
<th>Cost (EUR) per FSI saved (rounded)</th>
<th>BCR Range (Mean of means)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run-off crash protection (eg barrier or clearzone)</td>
<td>9,909km</td>
<td>6,846</td>
<td>2,368m</td>
<td>822m</td>
<td>120,000</td>
<td>1-16 (5)</td>
</tr>
<tr>
<td>Loss of control mitigation (eg shoulder sealing, lane widening)</td>
<td>3,702km</td>
<td>3,160</td>
<td>1,286m</td>
<td>871m</td>
<td>275,000</td>
<td>1-2 (&gt;1)</td>
</tr>
<tr>
<td>Head-on crash protection or avoidance (eg barrier or 2+1 with separation)</td>
<td>859km</td>
<td>1,502</td>
<td>498m</td>
<td>270m</td>
<td>180,000</td>
<td>1-12 (4)</td>
</tr>
<tr>
<td>Intersection upgrading (principally protected turn)</td>
<td>1,096 sites 13km</td>
<td>1,412</td>
<td>535m</td>
<td>114m</td>
<td>81,000</td>
<td>1-45 (11)</td>
</tr>
<tr>
<td>Pedestrian provision along (footpath)</td>
<td>1,258km</td>
<td>743</td>
<td>266m</td>
<td>113m</td>
<td>358,000</td>
<td>1-14 (4)</td>
</tr>
<tr>
<td>Pedestrian provision across (crossing)</td>
<td>403 sites</td>
<td>102</td>
<td>36m</td>
<td>10m</td>
<td>98,000</td>
<td>1-8 (3)</td>
</tr>
<tr>
<td>Bicyclist provision (either on-road or off-road)</td>
<td>74km</td>
<td>38</td>
<td>13m</td>
<td>4m</td>
<td>93,000</td>
<td>3-7 (5)</td>
</tr>
<tr>
<td>Mixed combination (eg surfacing improvement)</td>
<td>817km</td>
<td>262</td>
<td>91m</td>
<td>34m</td>
<td>130,000</td>
<td>1-3 (2)</td>
</tr>
<tr>
<td>Total (mean)</td>
<td>--</td>
<td>14,065</td>
<td>5,092m</td>
<td>2,238m</td>
<td>(150,000)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

FSI – fatal and serious injury; PV – Present Value; m – millions; BCR – Benefit-Cost Ratio. Totals may not add due to rounding.
Appendix IV

Litman cautions against the simple approach used in Table 7:

“...this approach to estimating crash reduction ignores various new risks introduced by autonomous driving and mixed human- and autonomous-operated traffic. These include hardware and software failures, hacking, offsetting/risk compensation behaviour (the tendency of travellers to take additional risks when they feel safer), and dangers of platooning. Autonomous vehicles may reduce traffic congestion and pollution emissions, yet these benefits depend on vehicles operating in platoons on dedicated lanes. When traffic is mixed, with platoons driving at 60-100 km/hr next to congested lanes operating at 20-40 km/hr, drivers of conventional vehicles will be tempted to join these platoons, which can cause crashes. Some of the largest traffic safety gains during the last century resulted from seat belt use, yet autonomous vehicles are often portrayed with un-belted passengers sleeping in beds or playing cards at a table. This type of offsetting behavior is likely to increase crash severity.”

He argues that, in addition

“...almost all autonomous vehicle safety analysis reflects the old paradigm, which only measures distance-based risks and so ignores the additional crashes that result from policies and technologies that stimulate vehicle travel, and the safety benefits of vehicle travel reduction strategies. In this case, autonomous driving technologies are likely to stimulate more total vehicle travel unless implemented with policies, such as efficient road pricing, HOV (High Occupancy Vehicle) priority and Smart Growth development policies. Imagine, for example, if autonomous vehicles stimulate more sprawled development and public transit systems are abandoned, and roads are unpriced, so rather than paying for parking spaces vehicles simply circle around the block for hours, causing total vehicle travel and traffic congestion to increase. Even if per kilometer crash rates decline, total crashes might increase.”

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Tackling the Transition to Automated Vehicles I 31
“The transition to autonomous vehicles should be prepared and planned for now, but should not be a distraction from the life-saving work that can be done using conventional approaches to crash reduction.”