Synthesis title: Crash mitigation

Observatory main category: Vehicles

Other relevant syntheses to be consulted:

- Helmets (Riders)
- Seatbelts (Vehicles)
- Child Restraints (Vehicles)
- Injury Mitigation (Vehicles)
- Seat Belts (Compliance and the Law)
- Child restraints (Compliance and the Law)
- Helmets (Compliance and the Law)

Keywords:

Crumple Zones and Side Impact Protection, Air Bags, Head Restraints, Underrun Protection.

Key facts

- Frontal airbags reduce fatality risk in head-on RTIs; this benefit is substantially greater when the principal impact point is head-on rather than slightly offset.

  (J. Bean *et al.*, 2009)

- Side airbags are more effective in reducing injury during a side impact than seatbelts.

  (G. Intas and P. Stergiannis, 2011)

- Investigations have shown that improved side underrun protection systems could reduce fatalities to pedestrians and cyclists by about 45 per cent by filling the open space between wheels on heavy goods vehicles.

  (A. Avenoso and J. Beckmann, 2005)

- A well-adjusted and well-designed head restraint can limit the movement of the neck and support the head for a longer period in an RTI.

  (RoSPA, 2007)

- Today excellent opportunities for reducing the number of whiplash injuries exist with different types of road safety measures. Particularly, vehicle factors are known to be important in preventing whiplash injuries. These vehicle factors include the structural response of the vehicle, aspects of the seat and head restraint design.

  (ETSC, 2007)

Summary

This document has been compiled to highlight and summarise research regarding crash mitigation technologies which are commonly available. Crash mitigation is a field concerned with the hardware installed within vehicles or secured to the vehicle occupant, which can minimise injury in the event of a Road Traffic Incident (RTI). Typical crash mitigation technologies include:

- Structural elements (Crumple zones and side impact protection);
- Air Bags (including side and external airbags);
- Head Restraints (including research on whiplash);
- Underrun protection (involving the front, side and rear of Large Goods Vehicles);
- Seat Belts (including pre-tensioners and smart seat belts);
- Child Restraints; and,
- Helmets (Motorcycle and Pedal Cycle).

The crash mitigation technologies of seat belts, child restraints and helmets are discussed in detail in dedicated research syntheses. Structural elements are briefly discussed to highlight their importance and how the relative performance vehicles are assessed. However, the main focus of this document will be research associated with airbags, head restraints and underrun protection.

Compared to seat belts, airbags are a relatively recent safety addition to vehicles. Frontal airbags are designed as part of a safety system acting together with the vehicles seat belt and seat to provide a means of absorbing the energy of a vehicles impact, resulting in protection for the driver and front seat passengers from the potential effects of occupants head and upper torso striking the steering wheel or dashboard. This design is most effective during a head-on RTI. More recent developments have included side airbags, which are intended to provide protection for the occupants from side-on RTIs, a scenario in which three-point seat belts have minimal mitigating effects.

Airbags have also been designed to deploy from the outside of the vehicle in order to reduce injuries to motorcyclists and pedal cyclists. However, concerns have been raised regarding their limited usefulness and potential to inflict further injury. Conversely, research concerning airbags for pedestrians has been more positive and vehicle manufacturers are beginning to install this technology.

Head restraints are an undervalued crash mitigation technology, and have the potential to effect large-scale road safety improvements. Head restraints, when correctly positioned, can reduce the likelihood of whiplash to occupants of vehicles which are struck during a rear striking RTI. Whilst there is a legal requirement for vehicles to have head restraints fitted in the UK, there are problems with occupants having them configured at an incorrect height; consequently they have minimal effect in mitigating whiplash.

The final crash mitigation technology discussed in this synthesis is underrun protection. Underrun occurs when a Large Goods Vehicle (LGV) or other large vehicle turns and causes smaller vehicles or pedestrians to become trapped between the axles and wheels of that vehicle. Side underrun protection consists of filling the space between the axles of a large vehicle so that smaller road vehicles cannot accidentally enter the area. Front and rear underrun protection involves a similar approach in that the area beneath the front and rear lights of a large vehicle is filled to create a solid environment that is akin to a smaller vehicle striking an immovable object (such as a wall). Whilst this might sound dangerous, it is less likely to cause injury, especially to occupants of smaller vehicles.

Methodology

This synthesis consists of research identified as relating to the topic of Crash Mitigation within the category of Vehicles, focussing on general safety and RTI prevention.

This synthesis was compiled during August – September 2012.

Note
This review includes statistics from Reported Road Casualties Great Britain 2011, which were the latest available data when the review was written. More recent statistics are available in Reported Road Casualties Great Britain 2013, Reported Road Casualties Great Britain 2014 and Reported Road Casualties Great Britain 2015.

A detailed description of the methodology used to produce this review is provided in the Methodology section of the Observatory website at: http://www.roadsafetyobservatory.com/Introduction/Methods.

An outline of the steps taken to produce this synthesis is given below:

- **Identification of relevant research** – searches were carried out on pre-defined research (and data) repositories. As part of the initial search some additional information sources were also consulted, which included http://www.ingentaconnect.com. Search terms used to identify relevant papers included but were not limited to:
    - 'Passive vehicle safety';
    - 'Crash mitigation technologies';
    - 'Airbags';
    - 'Side airbags';
    - 'Pedestrian airbags';
    - 'Head restraints';
    - 'Whiplash';
    - 'HGV underrun protection';
    - 'Side underrun';
    - 'Front underrun'; and,
    - 'Rear underrun'.

  A total of 37 pieces of relevant research were identified.
- **Initial review of research** – primarily involved sorting the research items based on key criteria, to ensure the most relevant and effective items went forward for inclusion in this synthesis. Key criteria included:
    - Relevance – whether the research makes a valuable contribution to this synthesis, for example robust findings from laboratory controlled crash testing.
    - Provenance – whether the research is relevant to drivers, road safety policies or road safety professionals in the UK. If the research did not originate in the UK the author and expert reviewer have applied a sense check to ensure that findings are potentially relevant and transferable to the UK.

    - Age – priority given to the most up to date titles in the event of over-lap or contradiction.
    - Effectiveness – whether the research credibly proves (or disproves) the effectiveness of a particular crash mitigation technology or intervention.

  Following initial review 19 pieces of research were taken forward to form the basis for this synthesis.

- **Detailed review of research** – key facts, figures and findings were extracted from the identified research to highlight pertinent issues and interventions.
- **Compilation of synthesis** – the output of the detailed review was analysed for commonality and a synthesis written in the agreed format. Note that the entire process from identifying research to compiling the synthesis was conducted in a time-bound manner.
- **Review** – the draft synthesis was subjected to extensive review by a subject matter expert, proof reader and an independent Evidence Review Panel.

Please note that:

- Research material conducted in the United Kingdom was used where possible in the compilation of this document, however, where there was found to be insufficient material in a particular field, research from worldwide sources was used in order to provide as comprehensive coverage as possible.
- All referenced URL were correct at the time the initial research was conducted.

Key statistics

Crash mitigation technologies are designed to reduce the injury severity once an RTI has started to happen. Therefore, examination of what types of RTI occur, injuries involved and their prevalence, is relevant in understanding the relative importance of mitigating risk.

The following sections will therefore highlight publicly available statistics relating to types of RTIs which occur in the UK. Note: statistics relating to children are not discussed as child restraints are covered in a separate research synthesis.

Relevant casualty statistics

- In 2008, 2,528 people were killed in RTIs in Great Britain. About half the people killed were car occupants and just over one third of these car occupants were killed in side impacts.

  (M. Edwards *et al.*, 2010)

- Rear impacts to HGVs constituted 14.3 per cent of all car/HGV impacts and 18.3 per cent of fatal car/HGV impacts in 2008. The vast majority of these are likely to be frontal impacts for the cars involved, although some could involve cars sliding sideways or even rear-end-on into the HGV.

  (R. Minton and T. Robinson, 2010)

- In England:
  - 7,045 car occupants in 2011 were recorded as being seriously injured.
  - 4,810 car occupants (68 per cent) were seriously injured in RTIs that involved another vehicle.
  - 92 per cent of the 2,822 pedal cyclist RTIs involved another vehicle.
  - 75 per cent of the 4,737 motorcycle RTIs involved another vehicle.

  (DfT, 2012)

Note

This review includes statistics from Reported Road Casualties Great Britain 2011, which were the latest available data when the review was written. More recent statistics are available in Reported Road Casualties Great Britain 2013, Reported Road Casualties Great Britain 2014 and Reported Road Casualties Great Britain 2015.

Types of injury

The following figures highlight the prevalence of injury types following involvement in a RTI.

- Based on the primary diagnosis, the majority of road casualties sustained a fracture (51.4 per cent).
- Head and leg were the most common primary body regions injured, representing over 50 per cent of all primary injuries.
- Motorcycle users have the highest proportion of serious injuries, 24.7 per cent. The corresponding figure for all road users is 18.2 per cent.
- Car occupants have the highest proportion of minor injuries, 30.5 per cent of all injuries sustained. This is higher than the average for all road users (26.2 per cent), although not unexpected given car occupants are less vulnerable in a road RTI relative to pedestrians, motor and pedal cyclists.
- Generally, injured pedestrians or pedal cyclists over 65 have a higher likelihood of sustaining serious or critical injuries compared to other road user groups. This may be because they are generally more vulnerable to the hazards associated road RTIs.

(DfT, 2012)

The basic head restraint is a relatively simple but effective technology in preventing whiplash and other neck injuries in the event of an RTI. New developments in technology have led to the design of more sophisticated head restraints. These active head restraints are designed to provide protection to a range of occupant sizes without the need for the occupant to manually attend to their adjustment.

However, the number of insurance claims for whiplash is shown to be extensive. Research suggests that many vehicle occupants do not have their head restraints at the correct level.

- The insurance industry state that over 80 per cent of personal injury claims arising from motor vehicle RTIs are Whiplash Associated Disorders (WAD), and report that this totals around 250,000 injuries per year.

(RoSPA, 2007)

It should be noted that the percentage of whiplash claims in the UK are higher than in other European countries, and that to some extent this is believed to be due to fraudulent claims, which given the current lack of any means to objectively measure WAD, are almost impossible to disprove. New developments in technology have led to the design of more sophisticated head restraints. These active head restraints are designed to provide protection to a range of occupant sizes without the need for the occupant to manually attend to their adjustment.

Age of vehicle

Modern vehicles are more likely to incorporate the latest crash mitigation technologies and therefore are better able to reduce injury severity in the case of an RTI. This is in part supported by analysis conducted for DfT and is presented in the Road Casualty Statistics for 2011:

- The proportion of car occupants sustaining minor injuries varied little by age of car, suggesting all car occupants, regardless of the age of the car, were equally likely to sustain a less severe injury. For more serious and critical injuries, the proportions gradually increased as the age of the car involved in the RTI increased, suggesting car occupants with older vehicles were more vulnerable to serious injuries relative to car occupants with newer vehicles.

(DfT, 2012)

Research findings

Summaries of key findings from several research reports are given below. Further details of the studies reviewed, including methodology and findings, and links to the reports are given in the References section.

Vehicle structures

One of the earliest crash mitigation technologies was the incorporation of crumple zones - developed by a Mercedes-Benz engineer in the 1950s.

(Global NCAP, 2012)

These engineering solutions mitigate the effect of an impact during an RTI by absorbing the energy from the force of an impact. The resulting reduction in the forces acting on the occupants of the vehicle lessen the likelihood of harmful injury from the RTI.

Typically, vehicle structures which offer crash mitigation provide a means of rating a vehicles safety using through controlled crash testing. Euro NCAP is the predominant organisation in Europe providing consumers with information on the crash testing of vehicles. The Euro NCAP star rating system, where cars can score up to 5 stars, are comprised of scores relating to:

- Adult protection (driver and passenger);
- Child protection;
- Pedestrian protection; and,
- Safety assist technologies.

However, the ratings scores do not directly assess the performance of the structure, other than an assessment of the stability of the occupant cell. The majority of the scores relate to measurements taken during the test to see how well the vehicle meets a set of given injury criteria which are measured using anthropomorphic test devices.

Despite Euro NCAP being the main organisation providing consumer information relating to the crash testing of vehicles and their safety, it should be understood that only a limited number of vehicles and scenarios are tested. Frontal impact tests for example are conducted at 40 mph by NCAP as this is relevant for a large proportion of RTIs.

It should be noted that NCAP tests are not regulatory and there is no compulsion for manufacturers to build vehicles that perform well in such tests. However, there are requirements relating to crash testing of vehicles where the manufacturers have to meet a number of injury criteria in order to obtain a regulatory approval before placing vehicles into the marketplace.

It is considered that review of the research related to vehicle structures should not be considered in this synthesis due to the limited potential for the target audience to affect change in this area. However, the importance of vehicle structure crash mitigation systems should not be underestimated and any organisation or individual looking to reduce their ‘risk’ should consider the Euro NCAP crash test results carefully when procuring vehicles.

Airbags

Airbags are now a well established life-saving technology. They are autonomously deployed in the event of collision with another object,as part of an integrated system with seat belts and pre-tensioners, to prevent the head from striking the steering wheel or dashboard and causing brain, cranial or neck injury. Initially airbags were installed to provide protection for the driver of a vehicle in a frontal impact RTI; however, in recent years the installation of multiple airbags throughout the vehicle has become common in order to provide the occupants with greater protection from injury in a wider range of RTI scenarios. These include side airbags which deploy to protect the head and torso in the event of a side impact, additional airbags in the driver cockpit to protect the lower legs of the driver in a frontal impact, and airbags that deploy from the seatbelt itself to manage the movement of a belted occupant during an impact.

This section examines the key findings related to both frontal and side airbags and their effective combination when coupled with seat belt usage.

Airbags are relevant to the target audience as they are in-vehicle technology which can be 'switched off' in a minority of circumstances, for example when positioning a rear-facing child restraint on the passenger seat. Additionally, it is key that road users are aware of the importance of airbags to ensure that they are properly maintained when faults are discovered, and/or replaced according to the manufacturers guidelines.

- Although the majority of vehicles now have seatbelts and airbags installed, fatalities in the event of head-on RTIs still occur. It was found that the reason for this is either the extreme severity of the RTI or the nature of the impact between the vehicle and the object with which it is colliding. For example, striking a lighting pole or a solid wall at the same speed would have drastically different effects on the vehicle.
- Frontal airbags reduce fatality risk in head-on RTIs; this benefit is substantially greater when the principal impact point is head-on rather than slightly offset.

(J. Bean *et al.*, 2009)

Side airbags also play a valuable role in reducing the severity of RTIs.

- Side impact RTIs are more lethal than frontal RTIs, because the lateral aspect of most vehicles offers less distance for the opportunity for energy dissipation when compared with a frontal impact.
- Side airbags are more effective in reducing injury during a side impact than seatbelts.

(G. Intas and P. Stergiannis, 2011)

- In near-side impact multi-vehicle RTIs, front seat drivers and passengers in vehicles with side air bags have lower risk of head and thoracic injury than those in vehicles without.

(S. Moran, 2004)

- Side air bags designed to protect the head appear to be very effective in reducing mortality in nearside RTIs among drivers of passenger cars.
- Torso-only side air bags appear less protective than combination head/torso air bags.

(E. Braver and S. Kyrychenko, 2004)

Despite the positive comments stated previously regarding the effectiveness of airbags, it should be noted that there has also been some criticism.

- There have been cases where side airbag deployment may have caused serious injury where it would not otherwise have been expected. This is has been particularly noted when deployment of side airbags occur on the non-struck side and in some frontal impacts. This has shown that there is a need for future studies into injury mechanisms and side airbag deployment.

(A. Kirk *et al.*, 2003)

'Smart' airbags have been developed to further enhance the protection provided by the safety systems enabling them to be deployed in a manner that enables the system to tailor its reaction to match the needs of the occupant.

- Advanced air bags include 'smart' air bags and front and rear side 'curtain' air bags that provide greater protection than regular air bags for all passengers in the event of an RTI. Smart air bags detect passenger weight and proximity and tailor air bag deployment to passengers' needs.

(H. Hamid, 2007)

Airbags have also been developed to improve safety for other road users.

- Airbag studies have been conducted in the past relating to the potential for airbags to reduce injuries to motorcyclists involved in frontal impacts. However, concern has been raised about the limited potential in some RTIs and their negative effect in others.

(A. Avenoso and J. Beckmann, 2005)

Although airbags for motorbikes have proved problematic, there are now motorcycle jackets readily available that have an inbuilt airbag that helps protect motorcyclist vital organs, neck and spine in the event of an RTI. A majority of deaths in motorcycle RTIs are associated with injuries to these vital organs.

Head restraints

This section primarily examines the effects of whiplash on vehicle occupants and those who have incorrectly positioned head restraints. The structural design of more modern vehicles is shown as a possible contributory element to the increased claims of whiplash due to the stiffer nature of the vehicle. This stiffer structure has occurred as a result of designing vehicles to provide an occupant compartment that does not deform and cause injury to the occupants.

The introduction of active head restraints and manufacturer specific designs are also briefly examined.

Whiplash primarily affects vehicle users when struck from the rear, however, a head-on RTI can in some circumstances result in whiplash related injury.

- Whiplash injuries, properly referred to as Whiplash Associated Disorders (WAD), resulting from car RTIs are an increasing problem in Europe. Whiplash is the most commonly reported injury in motor vehicle RTIs and presents a high cost burden to the society in general.

(ETSC, 2007)

- The majority of Whiplash Associated Disorders occur when a vehicle has been struck from the rear, and this means that head restraints can be used as a counter measure in order to reduce both the likelihood and severity of an injury.

(The Royal Society for the Prevention of Accidents, 2007)

- Whiplash injuries from rear-end RTIs are common and, because of their prevalence, extremely expensive for society.

(B. O'Neill, 1999)

- Frontal impact victims suffered symptoms indistinguishable from those of rear impact victims.

(R. Minton *et al.,* 1999)

The design and adjustment of a head restraint can be a major factor in preventing or reducing WAD.

- A well-adjusted and well-designed head restraint can limit the movement of the neck and support the head for a longer period in an RTI.

(RoSPA, 2007)

- Seat and head restraint design is one of the most influential parameters when considering risk of neck injury.
- Also influential is head restraint geometry and their ability to lock in place once adjusted.

(ETSC, 2007)

- Safer modern cars have increased the likelihood of whiplash due to the more rigid structural nature. In a more stable car the collision force is transmitted in a different manner. The occupants absorb a greater force due to the increase in stiffness of the bumper and rear section of the vehicle, introduced to minimise the effects of low speed RTIs.
- Today, excellent opportunities for reducing the number of whiplash injuries exist with different types of road safety measures. Vehicle factors are known to be especially important in preventing whiplash injuries. These vehicle factors include the structural response of the vehicle and aspects of the seat and head restraint design.

- In some vehicle models, the seat changes form and position in order to reduce the effect of the collision impact on the neck. In other systems the head restraint moves forward to protect the neck when the head lags behind. Both of these systems have been shown to reduce the whiplash effect significantly.

(ETSC, 2007)

- The most encouraging aspect of head restraint design today is the acknowledgment that seat back and restraint stiffness and elasticity are also important; this is leading to the introduction of active head restraints.

(B. O'Neill, 1999)

Underrun protection

The concept of underrun consists of three primary categories. Side underrun occurs when a large goods vehicle turns, causing small vehicles and pedestrians to become trapped between the axles and/or beneath the wheels. Front and rear underrun tend to affect vehicles travelling in front of or behind a large goods vehicle. Mitigation technology is installed to prevent vehicles ability to encroach the area beneath a goods vehicle.

This section examines the key findings relating to performance of front and rear underrun. It appears that there is more research required in order to establish whether current underrun protection methods are performing as designed.

- The original intention of Rear Underrun Protection was to provide a rigid barrier that made collision with the rear of a Large Goods Vehicle (LGV) comparable to a collision with a solid wall. However, current Rear Underrun Protection is failing to achieve this objective at collision speeds where modern cars would be able to protect their occupants.
- Improving the design of Rear Underrun Protection such that they did not fail and did prevent underrun at these collision speeds would be expected to prevent a significant proportion of the fatalities currently recorded.

(R. Minton and T. Robinson, 2010)

- Of all road users, motorcyclists have by far the highest injury risks in the event of an underrun RTI. If an RTI occurs, 98 per cent of motorcyclists sustain injuries.
- Injuries to the legs of the motorcyclist occur in approximately 80 per cent of all RTIs involving motorcyclists.

(A. Avenoso and J. Beckmann, 2005)

How effective?

The following statements highlight the contributions various interventions have had towards road safety.

- An estimated 1,500 lives have been saved in the United States since the introduction of airbags in 1987 through 1995.

(G. Intas and P. Stergiannis, 2011)

- Head side airbags could give a 45 per cent risk of fatality reduction in near-side impact RTIs.
- Chest side airbags could give 11 per cent risk of fatality reduction in near-side impact RTIs.

(S. Moran, 2004)

- Investigations have shown that improved side underrun protection systems could reduce fatalities to pedestrians and cyclists by about 45 per cent by filling the open space between wheels on heavy goods vehicles.

(A. Avenoso and J. Beckmann, 2005)

Gaps in research

- The beneficial effects of good head restraint adjustment could not be clearly demonstrated, even for rear impact victims, where the benefits of a well-adjusted restraint should have been very clear.

(R. Minton *et al.,* 1999)

- Future research is needed to determine if side airbags reduce the risk of specific injuries (e.g., head and chest injury)

(S. Moran, 2004)

- The evidence available suggested that the mandatory fitment of Front Underrun Protection has not been demonstrated to result in a reduction in the severity of car occupant casualties in collision with the front of HGVs. However, it is not known whether this is because of inadequate data or a genuine lack of effect.

(W. Chislett and T. Robinson, 2010)

- No biomechanically based safety regulations exist, mainly as a consequence of the limited (or inconclusive) knowledge available on whiplash.

(M. van Ratingen *et al.*, nd)

References

Department for Transport research and statistics

Title: Reported Road Casualties in Great Britain: 2011 Annual Report
Author / organisation: Department for Transport **Date:** 2012 **Format:** Pdf **Link:** http://assets.dft.gov.uk/statistics/releases/road-accidents-and-safety-annual-report-2011/rrcgb2011-06.pdf **Free / priced:** Free
Objectives: Annual report on Road Traffic Incidents and casualties in the UK.
Methodology: N/A
Key findings: In England: • 7,045 car occupants in 2011 were recorded as being seriously injured. • 4,810 car occupants (68 per cent) were seriously injured in RTIs that involved another vehicle. • 92 per cent of the 2,822 pedal cyclist RTIs involved another vehicle. • 75 per cent of the 4,737 motorcycle RTIs involved another vehicle.
Themes: RTI
Comments: Robust statistics relating to RTIs in the UK.

Title: Reported Road Casualties in Great Britain 2013 Annual Report
Author / organisation: Department for Transport **Date:** 2014 **Format:** Pdf **Link:** https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/359311/rrcgb-2013.pdff **Free / priced:** Free
Objectives: Annual report on Road Traffic Incidents and casualties in the UK.
Methodology: N/A
Key Findings: In Great Britain: • 785 car occupants were killed in 2013, 2% fewer than in 2012, and 44% lower than the 2005/09 average. • 7,641 car occupants were seriously injured in 2013, 7% fewer than in 2012, and 34% lower than the 2005/09 average. • 101,361 car occupants were slightly injured in 2013, 8% fewer than in 2012, and 31% lower than the 2005/09 average. • Car occupants have seen the biggest overall improvement in fatality rate: their fatality rate in 2013 was over 40 per cent lower than the 2005-09 average. • 19% of car occupants who were killed in 2013 were not wearing a seat belt (based on a sample of 232 car occupant fatalities for whom seat belt use was recorded). • Car occupants account for 46% of all road deaths.
Themes: RTI
Comments: Robust statistics relating to RTIs in the UK.

Title: Reported Road Casualties in Great Britain 2014 Annual Report
Author / organisation: Department for Transport **Date: 2015** **Format: Pdf** **Link:** **https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/463797/rrcgb-2014.pdf** **Free / priced: Free**
Objectives: Annual report on Road Traffic Incidents and casualties in the UK.
Methodology: N/A
Key Findings: In Great Britain in 2014: • 797 car occupants were killed, 2% more than in 2013, but 43% lower than the 2005/09 average. • 8,035 car occupants were seriously injured, 5% more than in 2013, but 31% lower than the 2005/09 average. • 106,698 car occupants were slightly injured, 5% more than in 2013, but 28% lower than the 2005/09 average. • Car occupants have seen the biggest overall improvement in fatality rate: their fatality rate in 2014 was over 40% lower than the 2005-09 average. • 21% of car occupants who were killed in 2013 were not wearing a seat belt (based on a sample of 336 car occupant fatalities for whom seat belt use was recorded). • Car occupants account for 45% of all road deaths.
Themes: RTI
Comments: Robust statistics relating to RTIs in the UK.

Other works

Title: Crumple zones
Author / organisation: Global NCAP **Date:** 2012 **Format:** HTML **Link:** http://www.globalncap.org/crumple-zones/ **Free / priced:** Free
Objectives: History of Crumple Zones.
Methodology: N/A
Key Findings: • One of the earliest crash mitigation technologies was the incorporation of crumple zones; developed by a Mercedes-Benz engineer in the 1950s.
Themes: Crumple Zone
Comments: Useful source for introduction to vehicle safety technology.

Title: How safe are the airbags? A review of literature
Author / organisation: G. Intas and P. Stergiannis (Health Science Journal) **Date:** 2011 **Format:** Pdf **Link:** http://www.hsj.gr/volume5/issue4/543.pdf **Free / priced:** Free
Objectives: The aim of this study was to review the dangers that result from the incorrect use of airbags.
Methodology: A thorough review, included bibliography research from both the review and the research literature in different databases was done, such as pubmed, scopus and heallink.
Key Findings: • Side RTIs are more lethal than the frontal RTIs, because the lateral aspect of most vehicles offers less opportunity for energy dissipation when compared with the front (that includes the bumpers, the fenders and the engine compartment). • Side airbags are designed to protect specific occupant body regions, namely the head and thorax, by 75 per cent and 68 per cent respectively. • Side airbags are more effective in reducing injury during a side impact than seatbelts. • An estimated 1,500 lives have been saved since the introduction of airbags in 1987 through 1995.
Themes: Airbag, Side Airbag, Side Impact
Comments: Medical perspective in to the safety issues relating to airbags.

Title: Investigating the real-world effectiveness of introducing mandatory fitment of front underrun protection to heavy goods vehicles
Author / organisation: W. Chislett and T. Robinson (TRL) **Date:** 2010 **Format:** Pdf **Link:** https://trl.co.uk/reports/PPR515 **Free / priced:** Free
Objectives: To undertake an analysis of STATS19 data & the Heavy Vehicle Crash Injury Study (HVCIS) fatal RTI database to investigate the actual real-world effect of fitment of Front Underrun Protection (FUP) on RTI outcome.
Methodology: Update the analysis previously undertaken to include data from RTIs occurring between 2003 and 2008 inclusive, and perform and in-depth investigation of factors that can influence the effect that FUP is having on the road casualty population.
Key Findings: • The evidence available suggested that the mandatory fitment of FUP has not resulted in a reduction in the severity of car occupant casualties in RTIs with the front of HGVs. • However, it is not known whether this is because of inadequate data or a genuine lack of effect.
Themes: HGV Underrun
Comments: The statistical power of this analysis is low because the number of vehicles equipped with FUP is low.

Title: Side Impact Safety
Author / organisation: M. Edwards, D. Hynd, R. Cuerden, A. Thompson, J. Carroll and J. Broughton (TRL) **Date:** 2010 **Format:** Pdf **Link:** https://trl.co.uk/reports/PPR501 **Free / priced:** Free (Login required)
Objectives: To provide the UK input to the WG13/21 subgroup benefits and costs analysis activity. To perform a series of three crash tests to determine the implications of an AE-MDB (Advanced European Mobile Deformable Barrier) test with a higher test speed. To assess the performance of WorldSID. To investigate related side impact issues. To provide technical support at EEVC WG13 meetings. To disseminate the results of this work to DfT.
Methodology: A variety of tests were undertaken in order to establish the implications of an AE-MDB test at higher speeds.
Key Findings: • In 2008, 2,528 people were killed in road traffic RTIs in Great Britain. About half the people killed were car occupants and just over one third of these car occupants were killed in side impacts.
Themes: Side Impacts
Comments: An in-depth study in to Advanced European Mobile Deformable Barriers and how improvements can be made to vehicles in order to meet the requirements of such a test. UK-based, in-depth study.

Title: Rear underrun protection for heavy goods vehicles: the potential effects of changes to the minimum technical requirements

Author / organisation: R. Minton and T. Robinson (TRL)
Date: 2010
Format: Pdf
Link: https://trl.co.uk/reports/PPR517
Free / priced: Free

Objectives: To review the UK evidence relating to the effectiveness of existing Rear Under-run Protection (RUP) and to assess the likely effectiveness of a range of potential changes to the regulations.

Methodology: Analysis of STATS19 RTI data; Analysis of HVCIS in-depth fatal RTI data; A brief review of recent literature.

Key Findings:

- In 2008 3.8 per cent of all RTIs involving a car and at least one other vehicle involved a car and a HGV. These RTIs accounted for 8.9 per cent of the car occupants killed in such RTIs, indicating that impacts with HGVs are much more dangerous for car occupants than impacts with other vehicles.
- Rear impacts to HGVs constituted 14.3 per cent of all car/HGV impacts and 18.3 per cent of fatal car/HGV impacts in 2008. The vase majority of these are likely to be frontal impacts for the cars involved, although some could involve cars sliding sideways or even rear-end-on into the HGV.
- The original intention of RUP was to provide a rigid barrier that made collision with the rear of a Large Goods Vehicle (LGV) comparable to a collision with a solid wall. However, current RUP are failing to achieve this objective at collision speeds where modern cars would be able to protect their occupants.
- Improving the design of RUP such that they did not fail and did prevent underrun at these collision speeds would be expected to prevent a significant proportion of the fatalities currently recorded.

Themes: HGV Underrun

Comments: UK-based study evaluating STATS19 RTI data. Highly relevant statistical material.

Title: Fatalities in Frontal Crashes Despite Seat Belts and Air Bags
Author / organisation: J. Bean, C. Kahane, M. Mynatt, R. Rudd, C. Rush and C. Wiacek (National Highway Traffic Safety Administration) **Date:** 2009 **Format:** Pdf **Link:** http://www-nrd.nhtsa.dot.gov/pubs/811102.pdf **Free / priced:** Free
Objectives: To explore more detailed data from the Crashworthiness Data System of the National Automotive Sampling System and quantify how often various phenomena are occurring to make frontal RTIs fatal despite belts and air bags.
Methodology: Case study/analysis.
Key Findings: • Fatalities in frontal RTIs to belted occupants at seats equipped with frontal air bags are now commonplace for the simple reason that most people buckle up and most of the vehicles on the road are equipped with air bags. • Fatality Analysis Reporting System (FARS) data suggests there were 4,835 such fatalities in [the US in] 2007. • Frontal air bags reduce fatality risk in frontal RTIs, but substantially more when the principal impact point is head-on rather than slightly offset.
Themes: Air Bags
Comments: This is a US-based study, therefore the statistical material may only have limited usage for the UK.

Title: Cars in the Future
Author / organisation: The Royal Society for the Prevention of Accidents **Date:** 2007 **Format:** Pdf **Link:** http://www.rospa.com/rospaweb/docs/advice-services/road-safety/vehicles/cars-in-the-future.pdf **Free / priced:** Free
Objectives: This paper seeks to explore how driving will change in the future due to the advances in technology, and how it interacts with the driver. It will look at what predicted casualty savings we can expect from new technology, as well as how quickly it will spread into the market.
Methodology: The policy paper is not intended to look at technical engineering issues, nor is it an in depth literature review of any of the technologies which it discusses. It will look at how technology will change the way cars and the roads are used as well as looking at and raising key issues which need addressing from literature and scientific studies, in order to facilitate a smooth introduction of vehicle safety systems.
Key Findings: • The insurance industry state that over 80 per cent of personal injury claims arising from motor vehicle RTIs are Whiplash Associated Disorders, and report that this totals around 250,000 injuries per year. • The majority of Whiplash Associated Disorders occur when a vehicle has been struck from the rear, and this means that head restraints can be used as a counter measure in order to reduce both the likelihood and severity of an injury. • A well-adjusted and well-designed head restraint can limit the movement of the neck and support the head for a longer period in an RTI. • Booster child seats with side wings can reduce the risk of injury to children in a side impact, as they help to contain the head and prevent it from hitting an intruding vehicle of the interior of the car.
Themes: Head Restraints, Whiplash, Child restraints
Comments: A policy paper, but highlights some important points relating to head and child restraints.

Title: Reining In Whiplash: Better Protection for Europe's Car Occupants

Author / organisation: European Transport Safety Council
Date: 2007
Format: Pdf
Link: http://www.etsc.eu/documents/ETS%20008-071.pdf
Free / priced: Free

Objectives: This ETSC policy paper on 'Reining in whiplash: Better Protection for Europe's Car Occupants' brings together arguments on why whiplash injuries are an increasing social and financial problem to European society and what can be done to tackle this major road safety issue.

Methodology: The policy paper explains what whiplash injuries are and how they occur by bringing evidence together from current state-of-the-art research programmes on whiplash.

Key Findings:

- Whiplash injuries, also called Whiplash Associated Disorders (WAD), resulting from car RTIs are an increasing problem. Whiplash is the most commonly reported injury in motor vehicle RTIs and presents a high cost burden to the society in general.
- Whiplash is more likely to affect the driver of a vehicle, rather than the passengers, as they instinctively lean forward towards the steering-wheel rather than the head restraint at the point of impact.
- Safer modern cars have increased the likelihood of whiplash due to the more rigid structural nature. In a more stable car the collision force is transmitted in a different manner, and the driver and passengers absorb a part of this force at the same time as they avoid being seriously crushed.
- Today excellent opportunities for reducing the number of whiplash injuries exist with different types of road safety measures. Particularl vehicle factors are known to be important in preventing whiplash injuries. These vehicle factors include the structural response of the vehicle, aspects of the seat and head restraint design.
- Seat and head restraint design is one of the parameters most influencing neck injury risk.
- Seat stiffness, strength and geometry are of vital importance in injury causation.
- Also influential is head restraint geometry and their ability to lock in place once adjusted.
- In some vehicle models, the seat changes form and position in order to reduce the effect of the collision impact on the neck. In other systems the head restraint moves forward to protect the neck when the head lags behind. Both of these systems have been shown to reduce the whiplash effect significantly.

Themes: Whiplash, Head Restraint

Comments: Policy paper but a good source of information on Whiplash using European data.

Title: The NHTSA's Evaluation of Automobile Safety Systems: Active or Passive?
Author / organisation: H. Hamid (Duval & Stachenfeld LLP) **Date:** 2007 **Format:** Pdf **Link:** http://www.luc.edu/law/activities/publications/clrdocs/vol19issue3/haroon_hamid.pdf **Free / priced:** Free
Objectives: Framework suggestion to the NHTSA.
Methodology: Review of passive and active safety systems.
Key Findings: • All vehicles in the U.S. are required to pass mandated Crashworthiness tests before they are sold to the public. • Crashworthiness includes vehicle design and the use of advanced metal alloys in vehicle construction. Thus, improved Crashworthiness results in better protection for vehicle occupants. • The air bag, a Passive system which is now mandatory in every new automobile sold in the U.S works in conjunction with the seat belt to provide two levels of safety in the event of a RTI. • Advanced air bags include 'smart' air bags and front and rear side 'curtain' air bags that provide greater protection than regular air bags for all passengers in the event of an RTI. Smart air bags detect passenger weight and proximity and tailor air bag deployment to passengers' needs.
Themes: Airbags, Crashworthiness
Comments: US only objective review of crashworthiness tests – may be of limited use to UK due to differing test standards.

Title: Fact Sheet: The Safety of Heavy Duty Vehicles
Author / organisation: European Transport Safety Council **Date:** 2005 **Format:** Pdf **Link:** http://www.etsc.eu/documents/FS_HDV.pdf **Free / priced:** Free
Objectives: To highlight the various safety factors relating to drivers of heavy duty vehicles.
Methodology: Literature review in to the various safety factors relating to drivers of heavy duty vehicles.
Key Findings: • The dimensions of coaches and LGVs usually provide drivers of heavy vehicles with greater protection against injury in RTIs than occupants of smaller vehicles. • Seat belts in heavy duty vehicles are intended both at drivers and passengers to reduce the probability of injury to them and to make the injuries which occur at least less severe.
Themes: Seat-belts, Heavy Duty Vehicles
Comments: Compilation of previous ETSC work, but highlights important points.

Title: The Safety of Vulnerable Road Users in the Southern, Eastern and Central European Countries (The "SEC Belt")

Author / organisation: A. Avenoso and J. Beckmann (European Transport Safety Council)
Date: 2005
Format: Pdf
Link:
http://www.etsc.eu/documents/The%20Safety%20of%20Vulnerable%20Road%20Users%20in%20the%20Southern,%20Eastern%20and%20Central%20European%20Countries%20(The%20SEC%20Belt).pdf
Free / priced: Free

Objectives: Policy Paper

Methodology: This ETSC Policy Paper on the protection of vulnerable road users in the EU member states where the risks to road users are higher is part of ETSC's publications series. In addition to the periodic ETSC Monitors, this series comprises the ETSC Reviews, the ETSC Policy Papers and the ETSC Fact Sheets.

Key Findings:

- Investigations have shown that improved side underrun protection systems could reduce fatalities to pedestrians and cyclists by about 45 per cent by filling the open space between wheels on heavy goods vehicles.
- Of all road users, motorcyclists have by far the highest injury risks. If an RTI occurs, 98 per cent of motorcyclists sustain injuries.
- Injuries to the legs of the motorcyclist occur in approximately 80 per cent of all RTIs.
- In RTIs in which the motorcyclist collides into another party, there is only a secondary impact of force on the legs. In this case, the head and upper torso are the first to make contact with the other party. In this situation, crash test results have indicated that motorcycle leg protectors, while effectively protecting the lower extremities, could have a negative effect on the risk of head injury by influencing the path of movement.
- Airbag studies have been conducted in past relating to the potential for airbags to reduce injuries to motorcyclists involved in frontal impacts. However, concern has been raised about the limited potential in some RTIs and their negative effect in others.
- Full framed chassis motorcycles have shown that it is possible to greatly enhance the passive safety of motorcyclists without jeopardizing the manoeuvrability and small space requirements of motorcycles. Furthermore, the absence of helmet requirements helps motorcyclists to have full lateral vision as other road users.

Themes: LGV Underrun, Motorcyclist Protection

Comments: Policy paper based on European statistics.

Title: Efficacy of Side Air Bags in Reducing Driver Deaths in Driver-Side Collisions
Author / organisation: E. Braver and S. Kyrychenko (Insurance Institute for Highway Safety, Virginia, USA) **Date:** 2004 **Format:** Pdf **Link:** http://dx.doi.org/10.1093/aje/kwh087 **Free / priced:** Free
Objectives: To establish the effectiveness of side air bags in preventing US driver fatalities.
Methodology: RTIs involving cars struck on the driver's side were examined using data from the Fatality Analysis Reporting System (FARS) and the General Estimates System.
Key Findings: • Side air bags designed to protect the head appear to be very effective in reducing mortality in nearside RTIs among drivers of passenger cars. • Torso-only side air bags appear less protective than combination head/torso air bags.
Themes: Side air bags
Comments: US-based study and casualty statistics, but subject matter should prove useful to UK audience.

Title: Keeping Children Safe in Traffic
Author / organisation: Organisation for Economic Co-operation and Development/International Transport Forum **Date:** 2004 **Format:** Pdf **Link:** http://www.internationaltransportforum.org/Pub/pdf/04ChildrenSafeE.pdf **Free / priced:** Free
Objectives: This report aims to encourage a continuation of the progress achieved in children's road safety over the past two decades by drawing attention to successful programmes and strategies that can be tailored and adopted by OECD countries.
Methodology: The report begins with an assessment of the scale and current understanding of the nature of child road safety (Chapter 1). Chapters 2, 3, and 4 explore new approaches, designs and strategies to increase children's safe mobility in the road environment. Chapter 2 describes the role that safety and education play in promoting children's safe behaviour on the road; Chapter 3 discusses how the built environment affects their safety, and Chapter 4 outlines safety equipment for a variety of travel modes.
Key Findings: • Modern vehicles are designed with energy-absorbing crumple zones to minimise deceleration, limit intrusion and so reduce injury. • The effect of the crumple zone is to minimise potential injury to occupants of the vehicle by reducing the amount of energy available to damage the passenger compartment.
Themes: Crumple Zones, Airbags
Comments: Report on child road safety initiatives from many countries worldwide. Relevant review to UK.

Title: Side Air Bags – Protection in Near Side Impacts
Author / organisation: S. Moran (Center for Injury Sciences, University of Alabama) **Date:** 2004 **Format:** Pdf **Link:** http://www.nhtsa.gov/DOT/NHTSA/NVS/CIREN/2003%2520Presentations/Alabama1203.pdf **Free / priced:** Free
Objectives: Study in to effectiveness of side-impact safety features in US cars.
Methodology: Review of vehicles involved in side impact RTIs and the injuries that can be caused.
Key Findings: • In near-side impact multi-vehicle RTIs, front seat drivers and passengers in vehicles with side air bags have lower risk of head & thoracic injury than those in vehicles without. • Head side airbag could give a 45 per cent risk of fatality reduction in near-side impact RTIs. • Chest side airbag could give 11 per cent risk of fatality reduction in near-side impact RTIs. • Future research is needed to determine if side airbags reduce the risk of specific injuries (e.g., head and chest injury).
Themes: Side Impact, Airbags, Side Airbags
Comments: Study Limitations: • Information on actual Side Airbags deployment not reliably available in CDS data files. • Thus, Side Airbags availability used as a surrogate for Side Airbags deployment. • Side Airbags as standard versus optional equipment. • Only front seat occupants were studied.

Title: Side Airbag Deployments in the UK – Initial Case Reviews
Author / organisation: A. Kirk and A. Morris (Loughborough University) **Date:** 2003 **Format:** Pdf **Link:** https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/1100/1/PUB257.pdf **Free / priced:** Free
Objectives: Presenting initial cases of deployment from the UK, including examples where there is some suggestion that side airbag deployment may have contributed to injury outcomes.
Methodology: The data for this work were collected as part of the UK Co-operative Crash Injury Study (CCIS) and the analysis covers cases investigated from 1998 to 2002. The CCIS study uses in-depth retrospective procedures involving vehicle examination and hospital medical data. The study also adopts a stratified sampling system such that nearly all 'fatal' RTIs, 80-90 per cent of the 'serious' RTIs (usually admission to hospital) and 20-30 per cent of 'slight' RTIs are investigated in selected regions of the UK. For a RTI to be investigated, at least one of the vehicles must be less than 7 years old, towed from the scene and contain at least one injured occupant. Injury outcome is assessed using the Abbreviated Injury Scale (AAAM, 1990). As the CCIS sample is biased towards more serious injury outcomes, only inferences of relative injury risk can be made about the whole UK population as a whole.
Key Findings: • Side airbag deployments are preventing injuries in the real world. • Side airbag deployment is taking place in cases where it would not be expected. Especially when the deployment is on the non-struck side and in some frontal impacts. • Cases have been found in this initial sample in which the RTI severity exceeded the protection capabilities of most modern safety systems. • Some cases are presented in which the side airbag deployment may have caused serious injury where it would not otherwise have been expected. This has shown that there is a need for future studies in to injury mechanisms and side airbag deployment.
Themes: Side Airbag, Side Impact
Comments: Qualitative and quantitative academic research paper produced in the UK.

Title: Head Restraints – The Neglected Countermeasure
Author / organisation: B. O'Neill (Insurance Institute for Highway Safety, Virginia, USA) **Date:** 1999 **Format:** Pdf **Link:** http://dx.doi.org/10.1016/S0001-4575(99)00057-3 **Free / priced:** $41.95
Objectives: Review of methods to minimise the differential head/torso movement and reduce the resulting injuries, focusing on the necessary first step for prevention, which is a head restraint that is behind and close to the back of an occupant's head during the RTI.
Methodology: The history of head restraints since the 1950s is reviewed, with particular attention to advanced restraint designs that are proving effective in reducing whiplash injury risk in dynamic tests using a new RTI test dummy neck and a new neck injury criterion.
Key Findings: • Whiplash injuries from rear-end RTIs are common and, because of their prevalence, extremely expensive for society. • After almost 30 years of neglect, auto-makers are finally taking head restraint design seriously. The most encouraging aspect of head restraint design today is the acknowledgment that seat back and restraint stiffness and elasticity also are important; this is leading to the introduction of active head restraints.
Themes: Head restraints, Whiplash
Comments: US-based study in to head restraints and Whiplash, therefore may be only of partial interest to UK audience.

Title: Whiplash Injury – Are Current Head Restraints Doing Their Job?
Author / organisation: R. Minton (TRL), P. Murray, W. Stephenson, C. Galasko (University of Manchester) **Date:** 1999 **Format:** Pdf **Link:** http://dx.doi.org/10.1016/S0001-4575(99)00092-5 **Free / priced:** Priced
Objectives: To determine whether any other factors, in addition to head restraint adjustment, could be found which would influence the severity of whiplash injury.
Methodology: This was done by linking medical assessment of real-world RTI victims with engineering assessment of the RTI vehicles. A random sample of road RTI victims suffering from whiplash associated disorder was studied. The vehicles they had been travelling in were examined to assess impact severity and, where possible, measurements were made of seat and head restraint adjustment with the subject sitting in the vehicle.
Key Findings: • Frontal impact victims suffered symptoms indistinguishable from those of rear impact victims. • The beneficial effects of good head restraint adjustment could not be clearly demonstrated, even for rear impact victims, where the benefits of a well-adjusted restraint should have been very clear.
Themes: Head restraints, Whiplash
Comments: UK-based study raising interesting points on head restraints.

Title: The Euro NCAP Whiplash Test
Author / organisation: M. van Ratingen, J. Ellway (Euro NCAP), M. Avery (Thatcham), P. Gloyns (VSC, on behalf of ICRT), V. Sandner (ADAC), T. Vermissen (TNO Science and Industry) **Date:** [no date] **Format:** Pdf **Link:** http://www.euroncap.com/files/Paper_09-0231---0-155567f6-80a9-4d6d-91b6-e1ca2656b132.pdf **Free / priced:** Free
Objectives: To highlight seats with known good and poor performance and to provide the maximum incentive to manufacturers to move towards best practice in seat design.
Methodology: Comprehensive seat test procedure described. For full details, refer to document.
Key Findings: • Whiplash neck injury, caused by sudden neck distortion, particularly occurs in low speed rear-end RTIs and is the most commonly reported injury in RTIs today. • No biomechanically based safety regulations exist, mainly as a consequence of the limited (or inconclusive) knowledge available on whiplash.
Themes: Emergency Braking
Comments: Description of the Euro NCAP whiplash test relating to vehicle seating.