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Identification of vehicle related risk factors

Deliverable 6.1

SafetyCube

SafetyCube

Identification of Vehicle related Risk Factors

Work package 6, Deliverable 6.1

Please refer to this report as follows:
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Executive Summary

The present Deliverable (D6.1) describes the identification and evaluation of vehicle related risk factors. It outlines the results of Task 6.1 of Work Package 6 (WP6) of SafetyCube, which aimed to identify and evaluate vehicle related risk factors and related road safety problems by (i) presenting a taxonomy of vehicle related risks, (ii) identifying "hot topics" of concern for relevant stakeholders and (iii) evaluating the relative importance for road safety outcomes (crash risk, crash frequency and severity etc.) within the scientific literature for each identified risk factor. To reach this objective, Task 6.1 has initially exploited current knowledge (e.g. existing studies) and existing accident data (macroscopic and in-depth) in order to quantify scenarios (defined in Work Package 8) related to the vehicle element. This information will help further on in WP6 to identify countermeasures for addressing these risk factors and finally to undertake an assessment of the effects of these countermeasures.

The identification of a comprehensive taxonomy of vehicle-related risks has been a challenge by itself. Most of the studied risk factors are related to the human behaviour and it is often difficult to dissociate the driver from their vehicle in the literature. Nevertheless, a specific taxonomy has been identified, based on expertise and some well-known issues. Because every vehicle type has its own characteristics (size, weight, agility ...), different uses, and moves on different types of infrastructure (roadway, sidewalk, path ...), the first level of this taxonomy has been established from various types of road users, i.e. vehicles, pedestrians and cyclists. The second level has been based primarily on each of these road user groups, while still trying to have some common main characteristics.

To evaluate the scientific literature, a methodology was developed in Work Package 3 of the SafetyCube project. WP6 has applied this methodology to vehicle risk factors. This uniformed approach facilitated systematic searching of the scientific literature, and consistent evaluation of the evidence, for each risk factor whatever the observed point of view (human, infrastructure or vehicle). The method included a literature search strategy, a 'coding template' to record key data and metadata from individual studies, and guidelines for summarising the findings (Martensen et al, 2016b). The main database used in the WP6 literature search was Scopus, with some risk factors utilising additional database searches (e.g. Google Scholar, Science Direct). Where a high number of studies were found, further selection criteria were applied to ensure the best quality studies were included in the analysis (e.g. key meta-analyses, recent studies, country origin, importance etc.).

Once the most relevant studies were identified for a risk factor, each study was coded within a template developed in WP3. Information coded for each study included vehicle types, basic study information, road user group information, study design, measures of exposure, measures of outcomes and types of effects. The information in the coded templates will be included in the relational database developed to serve as the main source of the Decision Support System (DSS) being developed for SafetyCube.

Once all studies were coded for a risk factor, a synopsis was created, synthesising the coded studies and outlining the main findings in the form of meta-analyses (where possible). Each synopsis consists of three sections: a two page summary (including abstract, overview of effects and analysis methods); a scientific overview (short literature synthesis, overview of studies, analysis methods and analysis of the effects), and finally supporting documents (details of literature search and comparison of available studies in detail, if relevant).

To enrich the background information (scenarios and general characteristics), injury accident data from a number of sources across Europe (i.e. LAB, BAAC and CARE/CADaS) was used.

After undertaking the literature search and coding of the studies, it was found that for some risk factors not enough detailed studies could be found to allow a synopsis to be written. These risk factors will not be displayed in the DSS. Nevertheless, the coded studies on the remaining risk factors will be included in the database to be accessible by the interested DSS users. At the start of each synopsis, the risk factor is assigned a colour code, which indicates how important this risk factor is in terms of the amount of evidence demonstrating its impact on road safety, defined in terms of increasing crash risk or severity. The code can either be Red (very clear increased risk), Yellow (probably risky), Grey (unclear results) or Green (probably not risky). In total, 14 risk factors were given a Red code (e.g. risk in frontal impact, side impact or rollover and compatibility for passenger cars), 11 were given a Yellow code (e.g. Vehicle design or Low NCAP rating for pedestrians), and 11 were given a Grey code (e.g. Crash or vehicle data for trucks, crash characteristics for PTW.).

Some limitations were identified, mainly due to difficulties of finding relevant published studies. It was not possible to evaluate the effects on road safety of all topics listed in the taxonomy.

The next task of WP6 is to begin identifying measures that will counter the identified risk factors. Most of the vehicle safety systems are oriented to passive safety to fit with this taxonomy (the target of the passive safety systems being to avoid or to mitigate injuries, up to a limited level of crash intensity). However, ADAS and active safety are built essentially to avoid accident configurations (not directly the causes or the risk having produced the situation) or to decrease the intensity of the crash.

1 Introduction

1.1 SAFETYCUBE

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative road safety Decision Support System (DSS) that will enable policy-makers and stakeholders to select and implement the most appropriate strategies, measures and cost-effective approaches to reduce casualties of all road user types and all severities.

SafetyCube aims to:

1. develop new analysis methods for (a) Priority setting, (b) Evaluating the effectiveness of measures (c) Monitoring serious injuries and assessing their socio-economic costs (d) Cost-benefit analysis taking account of human and material costs
2. apply these methods to safety data to identify the key accident causation mechanisms, risk factors and the most cost-effective measures for fatally and seriously injured casualties
3. develop an operational framework to ensure the project facilities can be accessed and updated beyond the completion of SafetyCube
4. enhance the European Road Safety Observatory and work with road safety stakeholders to ensure the results of the project can be implemented as widely as possible

The core of the project is a comprehensive analysis of accident risks and the effectiveness and cost-benefit of safety measures focusing on road users, infrastructure, vehicles and injuries framed within a systems approach with road safety stakeholders at the national level, EU and beyond having involvement at all stages.

Work Package 6

The objective of work package 6 is to analyse data, and implement developed methodologies (WP3) concerning accident risk factors and road safety measures related to the vehicle point of view. It examines accident risks and safety measures concerning all types of road users (passenger cars, heavy goods vehicle, powered two wheelers , etc.), including Vulnerable Road Users (VRU). Personal as well as commercial transportation aspects are taken into account.

Therefore, various data sources (macroscopic and in-depth accident data) and knowledge bases (e.g. existing studies) will be exploited in order to:

- Identify and rank risk factors related to the road use.
- Identify measures for addressing these risk factors.
- Assess the effect of measures.

The work on vehicle related risks and measures in road traffic is done according to the methodologies and guidelines developed in WP3 (Martensen et al., 2017). It will work in uniform and in parallel with the work packages dealing with human (WP4) and infrastructure (WP5) related risks and measures, monitored and steered by WP8.

All main results of WP6 will be integrated into the DSS and linked with each other (risk factors and measures) and with the outcomes of other work packages (WPs 4, 5, and 7).

1.2 PURPOSE AND STRUCTURE OF THIS DELIVERABLE

This deliverable reports on the work in Task 6.1. The overall aim of Task 6.1 was to identify vehicle related risk factors. This addresses one of the main objectives of the SafetyCube project by contributing towards the creation of an inventory of estimates of risk factors and safety effects.

The task also involved identifying a set of vehicle related accident scenarios and conducting in-depth accident analysis in relation to them, as well as consulting with stakeholders to identify knowledge gaps. The outcomes of this task will be the basis for the next step of identifying measures that will mitigate the risk factors.

This deliverable is dedicated to present the process of identifying, selecting, analysing and assessing road safety risk factors related to vehicles as well as their outcomes. The following steps were taken towards achieving the common purpose of SafetyCube and are described in detail in this deliverable:

- Identification of vehicle related risk factors – creation of a taxonomy.
- Consultation of relevant stakeholders for 'hot topic' identification.
- Coding of studies.
- Analysis of risk factors on the basis of coded studies.
- Accident scenarios analysis.
- Synopses of risk factors.

The main results of deliverable 6.1 will be a variety of systematically analysed risk factors, documented in risk factor 'synopses', which will be incorporated into the Safety Cube DSS and linked to corresponding road safety measures and cost-benefit-analyses of certain measures. As the synopses are very comprehensive, they form individual documents appended to this one and will be made available separately via the project website (www.safetycube-project.eu/) and on the DSS when it is launched. However, an overview of the risk factor-synopses can be found in this deliverable as well as all related abstracts.

The approach of this work differs slightly from the work on road users (human behaviour) and infrastructure. Instead of starting with the risk factor and analysing it for all vehicle types, it makes more sense when dealing with vehicles to start with the vehicle type. Therefore vehicle related risk factors have been analysed for each of the following vehicle categories – Bicycles, Powered Two Wheelers (PTW), Passenger Cars (PC), Light Goods Vehicles (LGV), trucks and buses. The pedestrian category was also added to this list in order to gather the pedestrian risk factors in the same category that otherwise would have been studied separately in every category of vehicle.

Most of the risk factors studied are related to the driver. The main challenge for WP6 was first to identify a specific taxonomy independent of the risk factors related to the human element and relevant enough for the point of view of the vehicle.

Chapter 2 will summarise the methodologies and procedures utilised in the identification and prioritisation of vehicle related risk factors. This will include developing a taxonomy of risk factors, identifying 'hot topic' priorities in road safety, and the implementation of the SafetyCube methodology in relation to vehicle risks. Chapter 3 will discuss the process of identifying key vehicle related accident scenarios and associated analyses of in-depth accident data. Chapter 4 will include the abstract of each synopsis and an indication of the available evidence for the risk factor, divided into the aforementioned vehicle categories. Finally chapter 5 will set out the general conclusions and next steps.

2 Identification and Prioritisation of Risk Factors

Within the SafetyCube project the term 'risk factor' refers to any factor that contributes to road accidents. Risk factors can have immediate influence on the accident occurrence, on the injury severity, or with mediation of a Safety Performance Indicator (SPI). All elements of the road system (Vehicle, Human, Environment) can be influenced by an accident risk factor. WP6 is dealing with those risk factors that are related to the vehicle point of view in road traffic.

2.1 TAXONOMY OF VEHICLE RELATED RISK FACTORS

The identification of a comprehensive taxonomy of vehicle-related risks has been a challenge by itself. Most of the studied risk factors are related to the human behaviour and it is often difficult to dissociate the driver from their vehicle in the literature. In the different analysis of accident data (including in-depth data), the contributing factors related to the vehicle (and similarly infrastructure factors) are under-represented compared with the human issues. As mechanical failures remain rare events, it is often very difficult to deeply analyse the vehicle after a crash, especially if it wasn't serious. Nevertheless, a specific taxonomy based on expertise and some wellknown issues has been identified. As recommended by the project, the taxonomy for the risk factor related to the vehicle is based on a three level structure.

Because every vehicle type has its own characteristics (size, weight, agility …), different uses, and moves on different types of infrastructure (roadway, sidewalk, path …), the first level of this taxonomy has been established from various types of road users:

- Pedestrian
- Bicycle
- Powered Two Wheeler / All-Terrain Vehicle
- Passenger car
- Light Commercial Vehicle or Light Goods Vehicle
- Truck / Bus

The second level has been based primarily on each of these road user groups, while still trying to have some common main characteristics.. This second level has been developed from the literature review, results on previous European project (such as SafetyNet (Wallén Warner et al., 2008), TRACE (Naing et al., 2007), DaCoTA (2012), etc.) and our expertise. Attempts have been made to harmonize this second level through the different vehicle categories when it was possible. The third level proposes more specific risk factors for each road user type.

The category 'Pedestrian' was later added to the initial list of vehicle types. The first reason for this was to harmonize with the risk factors studied in the WP4, which included pedestrians, and add the contribution from the point of view of the vehicle. WP4 approached from the point of view of the human behaviour, and parts of the specific accident characteristics connected to pedestrians and their interaction with the other road users (vehicles) were not tackled. The second reason was to gather the pedestrian risk factors in the same category that otherwise would have been studied in every category of vehicle.

Looking carefully at the WP4 and WP6 taxonomies some overlaps can be found, such as pedestrian or rider protective equipment. The main difference comes from the point of view used to tackle these risk factors, with WP4 taking into account the human behaviour and the use of the equipment aspects while WP6 deals with interaction between road users and with the protection (in terms of injury risk) brought by these equipment.

Table 1: Taxonomy of vehicle risks related to pedestrian.

Vehicle element	Risk factor	Specific risk factor
Pedestrian	**Prevalence of pedestrian factors in crash data**	Pedestrian accidents characteristics (pedestrian, impact, type of vehicle striking, time of crash, …)
		Injury level
	Vehicle design	Vehicle shape
	Crashworthiness	Pedestrian low star rating (NCAP)
	Visibility / Conspicuity	Prevalence with the presence of sight obstructions (parked vehicles, traffic, street furniture, uneven lighting condition, etc.)

Table 2: Taxonomy of vehicle risks related to Cyclist.

Vehicle element	Risk factor	Specific risk factor
Cyclist	**Prevalence of cyclist factors in crash data**	Accident characteristics (cyclist, vehicle striking, infrastructure, type of impact, time of crash…)
		Injury level
	Visibility / Conspicuity	Prevalence with the presence of sight obstructions (parked vehicles, traffic, street furniture, uneven lighting condition, etc.)

Table 3: Taxonomy of vehicle risks related to Powered Two Wheeler (PTW) and All –Terrain Vehicle (ATV)

Vehicle element	Risk factor	Specific risk factor
PTW / ATV	**Prevalence of PTW factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash …)
		Injury level
	Protective equipment design	Poor helmet performance
		other equipment
	Technical defects / Maintenance	Faulty headlights & taillights
		Problem related to tire
		Faulty steering system and suspension
		Faulty brakes

		Engine modification
	Visibility / Conspicuity	Visibility / Conspicuity / sight obstruction / small size

Table 4: Taxonomy of vehicle risks related to Passenger car

Vehicle element	Risk factor	Specific risk factor
Passenger Car	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Injury mechanism	Risk to be injured in frontal impact (driver, front passenger, rear passenger)
		Risk to be injured in rear impact
		Side impact : risk to be injured following nearside/farside impact
		Risk of injury in Rollover
		Risk of injury in single v/s multiple impacts
		Risk of injury in case of fire
		Risk for child
		Submarining & abdominal injury risk
		Risk of injury with airbag deployment (burn, blast, out of position, airbag generation, etc.)
		Load limiter with occupant characteristics (age, pregnant, gender, etc.)
		risk of occupant projection (against rigid part or interaction with occupants and/or restraint)
		risk of ejection (body or part of the body outside the vehicle)
	Crashworthiness	Compatibility (self protection / partner protection)
		Age of the vehicle
		Crash with animals
		Low star rating (EuroNCAP)
	Technical defects / Maintenance	Faulty headlights & taillights
		Tire blow out
		Faulty steering system and suspension
		Faulty brakes
		Airbag deployment at untimely moment

	Visibility / conspicuity	Blind spot issue
		Visibility limitation due to design (A-pillar, rear view, etc.)
	Specificities	Risk associated to SUV

Table 5: Taxonomy of vehicle risks related to Light Commercial Vehicle (LCV) or Light Goods Vehicle (LGV)

Vehicle element	Risk factor	Specific risk factor
LCV / LGV	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Crashworthiness	Compatibility (self protection / partner protection)
	Technical defects / Maintenance	Faulty headlights & taillights / retroreflective stripes
		Problems related to tire (blow out, defects, etc.)
		Faulty steering system and suspension
		Faulty brakes
		Load / Distribution of the load / cargo securing
	Visibility / conspicuity	Blind spot issue
		Visibility limitation due to design

Table 6: Taxonomy of vehicle risks related to Trucks or Bus & Coaches

Vehicle element	Risk factor	Specific risk factor
Trucks **Bus & Coach**	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Injury mechanism	Bus: Risk for unbelted occupants
		Risk with intrusion
		Risk of injury in case of fire
	Crashworthiness	Compatibility (self protection / partner protection)
		Risk for VRU
	Technical defects / Maintenance	Faulty headlights & taillights / retroreflective stripes
		Tire blow out
		Faulty steering system and suspension
		Faulty brakes

		Truck: Load / Distribution of the load / cargo securing
		Truck: Risk associated with transport of dangerous goods
	Visibility / conspicuity	Blind spot issue
		Visibility limitation due to design

3 Methodology for Evaluating Vehicle Related Risk Factors

This chapter provides an overview of the methodology developed in order to evaluate the scientific literature related to vehicle risk.

The aim was to collect information for each risk factor in as uniform a manner as possible. Therefore a standard methodology was developed within Work Package 3 of the SafetyCube project. This included developing a literature search strategy, a 'coding template' to record key data and metadata from individual studies, and guidelines for summarising the findings for each risk factor. Collating information from a variety of studies, each of which may use different underlying theories, designs and methods, represented a big challenge. Therefore the approach and 'coding template' developed was designed to be flexible enough to capture important information but also be able to facilitate the comparison between studies. Copies of these documents and the associated instructions and guidelines can be found in Martensen et al (2017).

3.1 STUDY SELECTION (OVERALL APPROACH)

3.1.1 Literature Search

For each of the identified risk factor topics a standardised literature search was conducted in order to identify relevant studies to include in the Decision Support System (DSS), and to form a basis for a concluding summary (synopsis) and further analyses. A standardised procedure was developed (led by WP3) and applied for each examined risk factor in SafetyCube (within WP4, 5, 6, 7). A closer examination of the literature search results for each risk factor culminated in adaptations of the risk factor taxonomy, especially on the second (risk factor) and third (specific risk factor) more detailed levels. The literature search was documented in a standard template to make the gradual reduction of relevant studies transparent. This documentation of each search is included in the corresponding supporting documents of the synopses.

The **main databases used** in WP6 are the following:

- Scopus
- Google Scholar
- Science Direct

3.1.2 Prioritising studies to be coded

The aim was to find studies that provided an estimate of the risk of being in a crash due to the presence of the risk factor. Therefore, studies considering crash data were designated the most important. However, while the actual occurrence of crashes can be seen as the ultimate outcome measure for road safety, Safety Performance Indicators (SPI) have in recent years been taken into consideration to quantify the road safety level (Gitelman et al., 2014). For some risk factors, studies considering SPIs are included in addition to those focusing directly on crashes.

Since the study design and the outcome variables are just basic criteria, for some risk factors the literature search had the potential to yield an excessive number of related studies and therefore additional selection criteria were adopted. Furthermore, on major and well-studied vehicle risk factors, meta-analyses were available and the results of these were identified and incorporated. While the aim was to include as many studies as possible for as many risk factors as possible, it was simply not feasible, given the scope and resources of the project, to examine all available studies for all risk factors and their variants. The criteria for prioritising studies to be selected for further analysis and eventual inclusion in the DSS were based on the following guideline:

- Key meta-analyses (studies already included in the meta-analysis were not coded again).
- Most recent studies.
- High quality of studies.
- Country origin: Europe before USA/Australia/Canada before other countries.
- Importance: number of citations.
- Language: English.
- Peer reviewed journals.

According to the level of detail of the topic and the history of research in the field, the number of studies that were eligible for 'coding' varied.

3.2 STUDY CODING

Within the aim of creating a database of crash risk estimates related to all risk factors studied in WP4 (human behaviour), WP5 (infrastructure) and WP6 (vehicle), a template was developed within WP3 to capture relevant information from each study in a manner that this information could be uniformly reported and shared across topics and WPs within the overall SafetyCube project. Guidelines were also made available for the task of coding with detailed instructions on how to use the template. The coding template was designed to accommodate the variety and complexity of different study designs. At the same time its complexity required partners to learn how to use it.

For each study the following information was coded in the template and will ultimately be presented in the DSS:

- Road system element (Road User, Infrastructure, Vehicle) and level of taxonomy so that users of the DSS will be able to find information on topics they are interested in.
- Basic information of the study (title, author, year, source, origin, abstract, etc.).
- Road user group examined.
- Study design.
- Measures of exposure to the risk factor.
- Measures of outcome (e.g. number of injury crashes).
- Type of effects.
- Effects (including corresponding measures e.g. confidence intervals).
- Biases.
- Summary.

For the full list of information provided per study see Martensen et al (2017).

Completed coding files (one per study) were uploaded to the DSS relational database.In total, more than 100 studies on vehicle related risk factors have been coded within WP6.

3.3 SYNOPSES CREATION

The DSS will provide information for all coded studies (see above) for various risk factors and measures. The synthesis of these studies will be made available in the form of a 'synopsis', indicating the main findings for a particular risk factor derived from meta-analyses or another type of comprehensive synthesis of the results (e.g. vote-count analysis).

The synopses aim to facilitate different end users: decision-makers looking for global estimates vs. scientific users interested in result and methodological details. Therefore, they contain sections for different end user groups that can be read independently. The structure of each risk factor synopsis, including the corresponding sub items (uniform for human, vehicle, and infrastructure related risk factors), is based on the following:

1. **Summary**
   i. Abstract
   ii. Overview of effects
   iii. Analysis methods
2. **Scientific overview**
   iv. Short synthesis of the literature
   v. Overview of the available studies
   vi. Description of the analysis methods
   vii. Analysis of the effects: meta-analysis, other type of comprehensive synthesis like vote-count table or review-type analysis
3. **Supporting documents**
   viii. Details of literature search
   ix. Comparison of available studies in detail (optional)

3.4 VEHICLE-RELATED CRASH SCENARIOS USING ACCIDENT DATA

To enrich the background information in the risk factor, accident data from the LAB (VOIESUR), BAAC (ONISR) and overview data from the CARE CADaS database was used.

3.4.1 Injury accidents database VOIESUR (LAB)

VOIESUR is the name of a French project funded by ANR (Agence Nationale pour la Recherche – the French National Research Agency) and Fondation MAIF. Four scientifically well-known and complementary organizations and research centres in Europe are involved in this project: CEESAR, CETE NC[1], IFSTTAR[2] and LAB. The main objective of this project was "*To reduce road accidents and injuries by identifying road safety issues or giving stakeholders knowledge to make decisions".*

The original goal of VOIESUR project is based on the in depth analysis of road accident reports in France in 2011, paper documents prepared by the police for injury accidents (PV) or fatal accidents (PVM). This is the wealth of information it contains that are particularly exploited in VOIESUR. In this project, all fatal police reports are collected and coded, along with all police reports of the Rhône department. However, regarding PV injury accidents, only 1 / 20 of the PV are randomly chosen and coded (for cost reasons and available worktime). 8,500 PV were coded in total.
The VOIESUR database [3,4]is composed of:

- 8,500 accidents (among which 3,500 are fatal accidents),
- 11,400 infrastructure elements,
- 14,000 vehicles, of which for 7,000 the initial speed has been estimated,
- 21,300 road users: 8,300 persons without any injury, 3,900 killed, 2,600 seriously injured, 6,500 slightly injured and 8,000 medical reports,
- 25,000 injuries,
- 16,000 collisions[3].

[1] Centre d'Etudes Techniques de l'Equipement Normandie Centre (today called CEREMA)
[2] Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux
[3] Collison refers to direct impact between vehicles or vehicle and object. Several collisions can occur in one accident.

Because not all injury accidents that occurred in France in 2011 were analysed, weighting factors have been calculated in order to estimate results at a national level. These weighting factors are based on the following criteria [2]:

- Type of road users.
- Presence of a third party in the accident.
- Type of Police (Gendarmerie, Police).
- Severity.
- Type of Road (RN, RD, Highway, etc).

3.4.2 BAAC Database

The database called BAAC[4] [5] is the national injury road accident census provided by the French ministry (ONISR[5]). Every year, all road injury accidents (any accident that occurred on a road open to the public traffic, involving at least one vehicle and having at least one injury) collected by the police are coded and gathered in this database. This database allows completion of the CARE database with the French figures. In this report the data for the year 2014 will be used.

3.4.3 CARE Accident database CADaS

Crash scenario analysis conducted using cases from the CARE Database considers all fatal accidents[6] recorded in year 2013. In total, records from 23,577 accidents which occurred in 28 European countries were analysed. The CARE Database comprises detailed data on individual accidents as collected by the Member States. Data are recorded according to a Common Accident Data Set (CADaS) consisting of a minimum set of standardised data elements, which allows for comparable road accident data to be available in Europe. Accident reports note all factors which were present at a crash. This does not mean that the noted factor was a contributory factor towards the crash. Note that, the risk factor is identified in relation to the involved party who was considered most at fault.

3.4.4 SafetyCube scenarios for all type of road users

The following results are based on the VOIESUR database provided by LAB and concern all types of vehicle. All injury accidents are considered. The following figures are based on the French data for the year 2011 (source VOIESUR).

If we look at the main scenarios (Figure 1) we can see that "Single vehicle accidents" are the most frequent configuration (21%), followed by "pedestrian accidents" (18.8%) and "Rear-End collisions or same traffic direction" (18.7%).

[4] Bulletin d'Analyse des Accidents corporels de la Circulation
[5] Observatoire National Interministériel de la Sécurité Routière
[6] Data refer to those accidents where at least a person was fatally injured (death within 30 days of the road accident, confirmed suicide and natural death are not included).

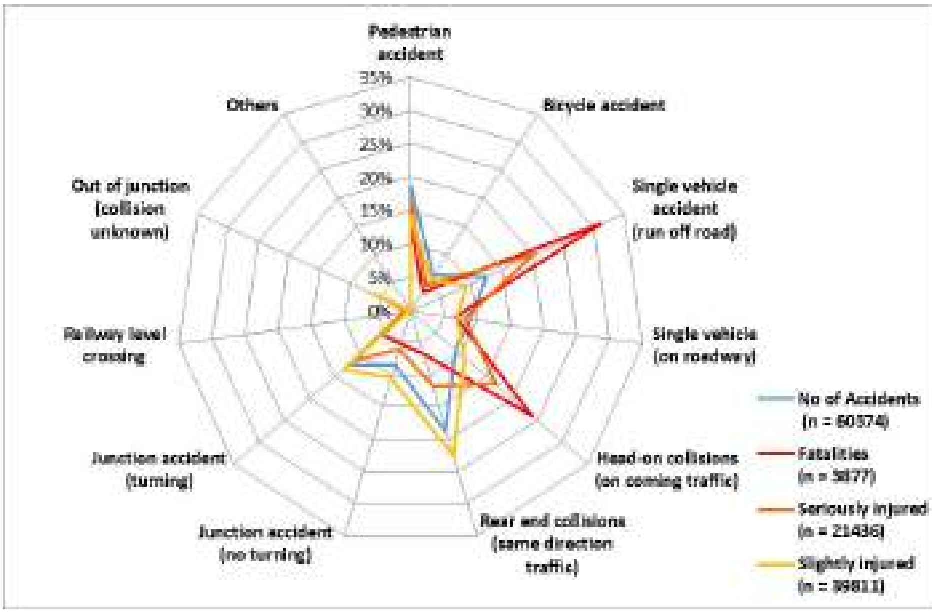


Figure 1 : Distribution of the SafetyCube scenarios according to the number of accidents and the severity (source: VOIESUR, France 2011)

In Figure 2, a closer look at "single vehicle accident" is made ("Single vehicle accidents" gathers the "run-off road" and "On roadway" scenarios), giving the distribution of the accidents and the associated severities among the "Single vehicle accidents" sub-scenarios.
The three most deadly sub-scenarios are: "Leaving the road nearside collision with object" (27%), "Leaving the road farside (collision with object)" (20%) and "Leaving the road nearside (without roll-over)" (12%).

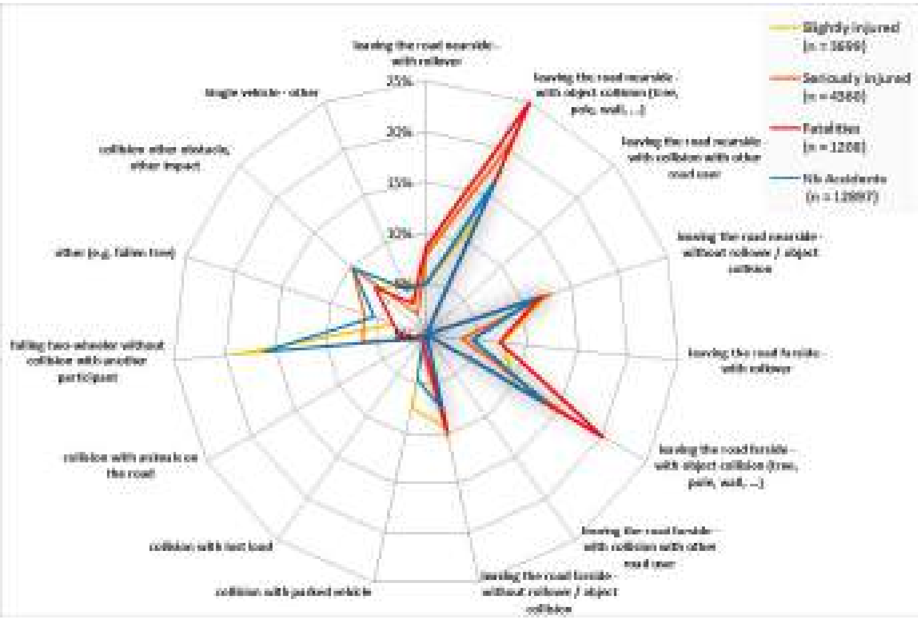


Figure 2 : Distribution of the severity according to the sub-level scenarios of single vehicle accident scenario (source: VOIESUR, France 2011)

Next we focus our results on sub-scenarios, i.e. corresponding to the overall scenarios included at the second level. The total number of sub-scenarios is 69.

The 10 most frequent sub-scenarios (Table 7) together represent 43% of the injury accidents. The three most frequent scenarios are: "Pedestrian crossing road in front of junction" (5.3%), "Rear-End collision or same traffic direction: lane changing vehicle" (5.22%) and "Pedestrian crossing the road behind the junction" (5.19%).

Rank (top 10)	Scenarios		Nb Accidents	% Accidents
1	Pedestrain : pedestrian crossing road in front of junction	1.3	3222	5%
2	RE collisions / same direction traffic : lane changing vehicle	6.4	3150	5%
3	Pedestrain : pedestrian crossing road behind junction	1.4	3136	5%
4	RE collisions / same direction traffic : - type of collision unknown, out of junction	6.9	2709	4%
5	Junction accident – turning : farside turn - other participant in opposite direction	8.2	2686	4%
6	RE collisions / same direction traffic : standing vehicle	6.1	2647	4%
7	RE collisions / same direction traffic : other	6.6	2341	4%
8	RE collisions / same direction traffic : breaking vehicle	6.2	2161	4%
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	2102	3%
10	Single Vehicle Accident (on roadway) : falling two-wheeler without collision with another participant	4.5	2084	3%

Table 7 : Top 10 most frequent accident scenarios
(Source VOIESUR, France 2011)

If we consider the most deadly sub-scenarios (Table 8), the first 10 scenarios together represent 52% of the fatalities. The three most frequent scenarios are: "Single vehicle accidents: leaving the road nearside (collision with object)" (9.4%), "Head-on collision or on-coming traffic (unintended lane change)" (8.0%) and "Single vehicle accidents: leaving the road farside (collision with object)" (7.6%).

Rank (top 10)	Scénarios		Fatalities	% Fatalities
1	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	366	9%
2	HO collisions / on coming traffic : front to front (unintended lane change stable)	5.2	310	8%
3	Single Aehicle Accident (Run off road) : leaving the road farside - with object collision (tree, pole, wall, ...)	3.6	294	8%
4	Single Aehicle Accident (Run off road) : leaving the road nearside - without rollover / object collision	3.4	174	4%
5	HO collisions / on coming traffic : side collision with other participant oncoming (loss of control)	5.4	169	4%
6	HO collisions / on coming traffic : front to front (unintended lane change instable)	5.3	166	4%
7	RE collisions / same direction traffic : - type of collision unknown, out of junction	6.9	157	4%
8	Single Aehicle Accident (Run off road) : leaving the road farside - without rollover / object collision	3.8	141	4%
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with rollover	3.1	127	3%
10	HO collisions / on coming traffic : other collision (unintended lane change instable)	5.6	113	3%

Table 8 : Top 10 most deadly accident sub-scenarios
(Source VOIESUR, France 2011)

The 10 most severe accidents (number of KSI[7] for 100 accidents) (Table 9) together represent 12% of the overall accidents and 26% of the KSI. The top three of this category are included in the "Head-On or on-coming traffic accidents" scenario. The first is "front to front with overtaking maneuver" (151 KSI for 100 accidents) followed by "Side collision with other participant oncoming (loss of control)" (126 KSI for 100 accidents) and "front to front with unintended lane change instable" (109 KSI for 100 accidents).

Rank (top 10)	Scenarios		Nb Accidents	KSI	KSI for 100 accidents
1	HO collisions / on coming traffic : front to front (overtaking)	5.1	335	506	151
2	HO collisions / on coming traffic : side collision with other participant oncoming (loss of control)	5.4	540	681	126
3	HO collisions / on coming traffic : front to front (unintended lane change instable)	5.3	845	924	109
4	Single Vehicle Accident (on roadway) : collision with lost load	4.2	44	44	100
5	Pedestrain : pedestrian sitting or lying on the ground	1.7	18	18	100
6	Single Aehicle Accident (Run off road) : leaving the road nearside - with rollover	3.1	648	612	95
7	HO collisions / on coming traffic : front to front (unintended lane change stable)	5.2	1537	1402	91
8	Single Aehicle Accident (Run off road) : leaving the road farside - without rollover / object collision	3.8	964	762	79
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	2102	1650	79
10	Single Vehicle Accident (on roadway) : collision with animals on the road	4.3	95	73	76

Table 9 : Top 10 of the most severe accident scenarios
(Souce VOIESUR, France 2011)

3.5 FINAL SYNOPSES

The full taxonomy of vehicle risk factors can be found in Chapter 2.1. In applying the method outlined in this chapter it was initially intended that each of the 59 specific risk factors would have a synopsis. However, following completion of the search and coding procedure it became apparent that for some specific risk factors there were insufficient code-able studies to justify the preparation of a synopsis.

[7] KSI : Killed and Severely Injured

4 Risk Factor Synopses - Abstracts

This chapter provides an overview of all vehicle related risk factor synopses that have been written as of October 2016 and these will be available through the DSS when it is launched in 2017. However, since these are very comprehensive documents, only the abstracts and the corresponding colour code - which indicates the level of evidence for a given risk factor - will be provided in this chapter. The synopses are intended to be periodically updated to reflect new research or in some cases to expand their scope. The full text of the synopses in their current form (v1.0) can be found in the appendix and any future updates or additions will be available on the project website (http://www.safetycube-project.eu/) and the DSS.

Full list of Synopses: [8]

- Pedestrian – Low NCAP
- Pedestrian – Vehicle Shape
- PTW – Accident characteristics
- LGV – Crashworthiness / Compatibility
- PC – Crashworthiness / Frontal impact

Because WP6 focuses its analysis on studies related to the vehicle, we decided to base our first level of the taxonomy on road users (vehicle) types. This first taxonomy level for WP6 is the following:

- Pedestrian
- Bicycle
- Powered Two Wheelers (all road vehicles included)
- Passenger car
- Light Goods Vehicle (LGV) or Light Commercial Vehicle (LCV)
- Truck or Heavy Goods Vehicles (HGV) and Bus & Coaches

In the following parts and for each road user (vehicle) type we will present first some general characteristics, secondly some illustrations related to SafetyCube scenarios, and finally a summary for each risk factor studied.

All risk factors listed in the WP6 taxonomy are not described here. Only risk factors with enough studies for a synopsis (a minimum of 5 eligible articles) are present.

4.1 RISK FACTORS RELATED TO PEDESTRIANS

From the CARE database (year 2014) the proportion of pedestrians represents approximatively 22% of the overall fatalities in the EU28 (figure below). Pedestrians represent the second highest proportion for fatalities, with passenger car occupants (45%) being the highest and motorcyclists being third (18%).

[8] The titles of the synopses are not always in line with the wording of the corresponding topics in the taxonomy. Some specific topics have been summarised in one synopsis. Sometimes the chosen synopsis title was better suited to the content and literature.

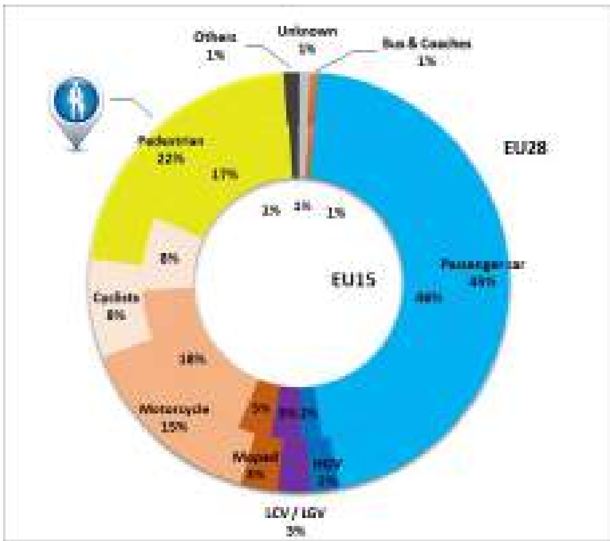


Figure 3 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

Among the European states, Romania, Latvia, Slovenia and Poland have the highest rate of fatalities (respectively with 38%, 37.5%, 34% and 34% of the overall fatalities of the country).

Figure 4 : Proportion of pedestrian fatalities according to European countries (source CARE, year 2014)

4.1.1 SafetyCube scenarios dedicated to pedestrians

We consider here all injury accidents involving at least one pedestrian. The following figures are based on the French data for the year 2011. For injury accidents involving at least one pedestrian, we can see here that the pedestrian is predominantly in collisions with a passenger car (69%) or a PTW (18%). If we look at the fatalities only, 62% are caused by a passenger car, 15% by a truck and 11% by a LCV/LGV.

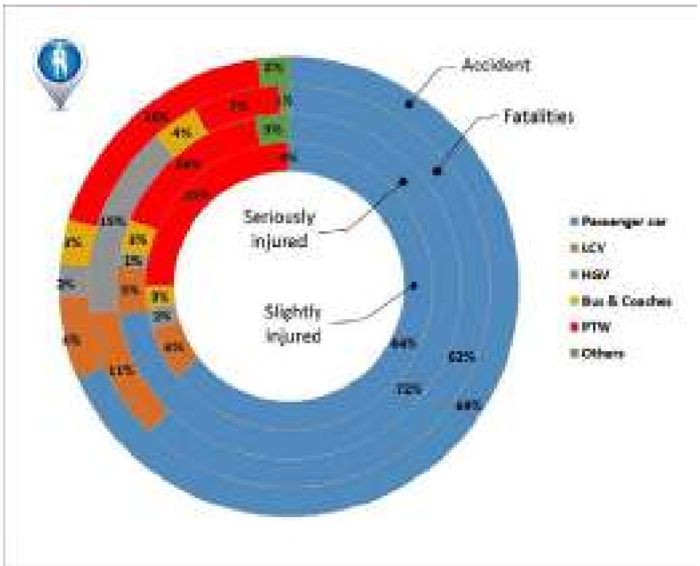


Figure 5 : Distribution of pedestrian accidents severity according to the type of road users involved (source VOIESUR, France 2011)

If we look at the distribution of the pedestrian injuries according to the body region in Figure 6 below, AIS3+[9] injuries (in red) are more frequent for the lower extremities (37%), the head (32%) and the thorax (14%). For the AIS2+[10] injury level (in orange) the three most frequently injured body regions are lower extremities (41%), the head (23%) and upper extremities (13%).

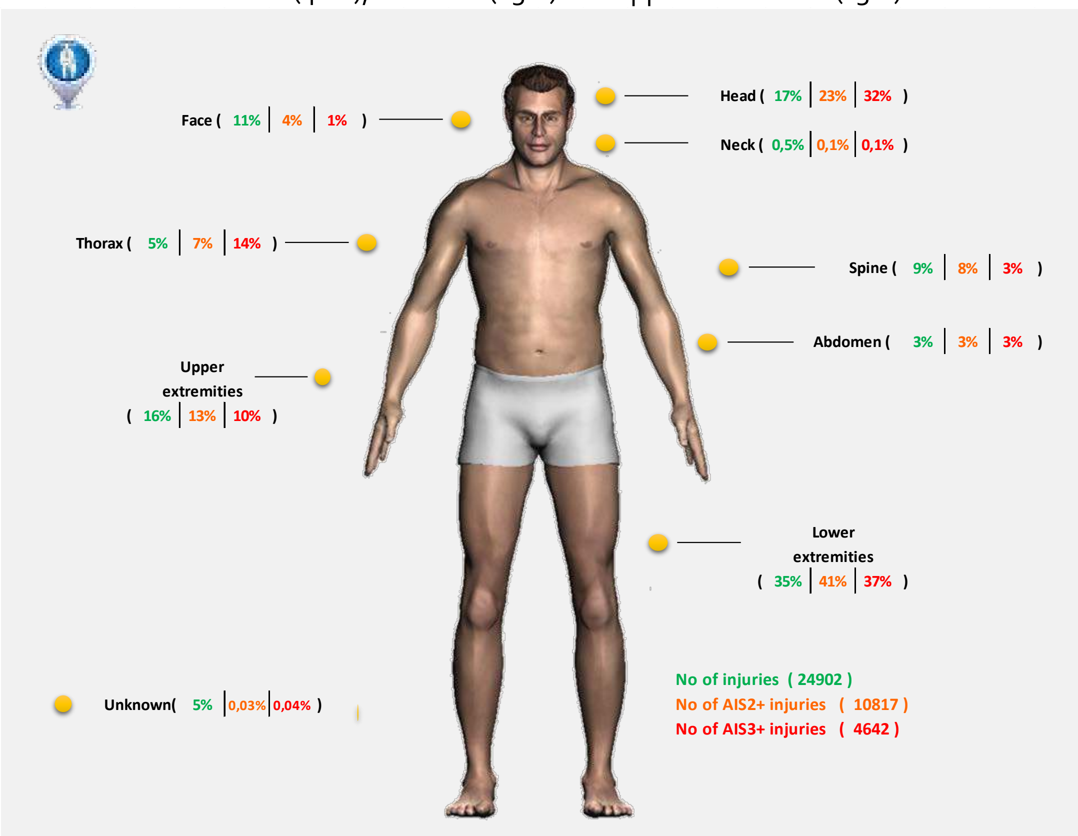


Figure 6 : Pedestrian: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

[9] AIS3+: All injuries with AIS ≥ 3.[1]
[10] AIS2+: All injuries with AIS ≥2

For this category of road user, the most frequent scenario is "pedestrian crossing road in front of junction" (28.4%), followed by "pedestrian crossing road behind junction" (27.7%) and "pedestrian crossing road out of crossing path" (12%).

The most deadly scenario is "pedestrian crossing road in front of junction" (21%) followed by "pedestrian crossing road out of crossing path" (19%) and "pedestrian moving along the road" (14%).

The most severe accidents (number of KSI per 100 accidents) are "pedestrian sitting or lying on the ground" (100 KSI), followed by "pedestrian moving along the road" (67 KSI), and "vehicle reversing" and "pedestrian crossing road on crossing path at straight stretch" (both with 39 KSI).

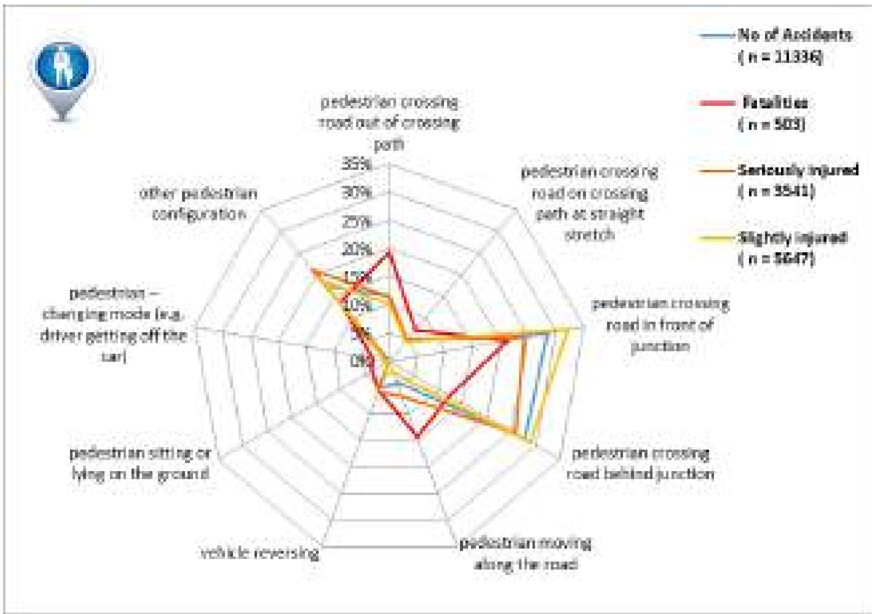


Figure 7 : Distribution of pedestrian accidents scenarios according to their severity (source VOIESUR, France 2011)

France 2011	Scenario no.	No of Accidents	Fatalities	Seriously injured	Slightly injured	KSI	KSI pour 100 accidents
pedestrian crossing road out of crossing path	1.1	1309	97	401	574	498	38
pedestrian crossing road on crossing path at straight stretch	1.2	546	36	174	252	210	39
pedestrian crossing road in front of junction	1.3	3222	107	860	1820	967	30
pedestrian crossing road behind junction	1.4	3136	62	910	1626	972	31
pedestrian moving along the road	1.5	462	72	238	129	310	67
vehicle reversing	1.6	592	28	202	160	230	39
pedestrian sitting or lying on the ground	1.7	18	18	0	1	18	100
pedestrian – changing mode (e.g. driver getting off the car)	1.8	82	15	5	48	20	24
other pedestrian configuration	1.9	1969	68	750	1038	818	42
	Total	***11336***	***503***	***3541***	***5647***	***4044***	***409***

Table 10 : Accident characteristics according to the pedestrian scenarios (Souce VOIESUR, France 2011)

4.1.2 Prevalence of pedestrian factors in crash data / Pedestrian characteristics

Colour Code: Red

This topic covers pedestrian factor characteristics widely reported in international literature. The main characteristics are age, gender, influence of alcohol or drugs and vision and hearing impairment.

Abstract

Many studies report pedestrian age as a contributory factor for involvement in a traffic collision. There is an observable higher involvement of younger pedestrians (under 15 years old), males between 15–24 years old and elderly pedestrians (Over 65 years old around 45% of the fatalities). The fatality rate for children is below the average rate for all pedestrians, whereas the fatality rate of the elderly is well above this average.

Older pedestrians are also over-represented in crashes at intersections, particularly those without traffic signals.Additionally they are more at risk of being struck by a turning vehicle. Older pedestrians are also overrepresented in crashes when they are crossing mid-block sections of roads, particularly on wide multi-lane roads, in busy bi-directional traffic.

Gender is also a risk factor in pedestrian collisions; two out of three pedestrians involved in a traffic accident are males. Other characteristics which have been found as contributory factors in this type of collision are alcohol or drug use which is a clear risk factor, in addition there is a higher risk of fatality for pedestrians with vision or hearing impairments or a sudden illness

Concerning the driver of the vehicle that struck the pedestrian, it has been found that younger (Under 25 years old) and older age drivers (>65 years old), and especially driving under the influence of alcohol, were related with a greater likelihood of colliding with a pedestrian. Other studies also found that drivers without a valid driving license and drivers who were driving alone had a greater risk of being involved in this type of accident.

4.1.3 Prevalence of pedestrian factors in crash data / Impact characteristics

Colour Code: Grey

There are many characteristics surrounding the types of pedestrian collisions , however is not clear if these are risk factors or contributory factors.

Abstract

Pedestrian traffic collisions occurred mostly in urban areas (around 60%-80%) however, when the accident is located in a non-built up area, the pedestrian have a higher risk of sustaining serious injuries. When the road layout is considered, approximately 70% of the accidents happened away from an intersection, 20% at intersections and 10% in other locations. Regarding the road type, some studies found that roads with two, undivided flows of traffic are more risky than the other types of roads

Lighting conditions are contributory factors, however it has great variability between countries. For example, in Ireland 94% of pedestrian collisions happened in darkness whereas in France only 35% were in darkness.

A clear risk factor is the speed limit. It has been identified in many studies that as the speed limit increases the risk of a run over accident increases as well.

Time and seasonality depends on the geographic zone, the working days, etc....The result of this is that even when it seems to be risk factors, there is large variability.

4.1.4 Prevalence of pedestrian factors in crash data / Type of vehicle striking

Colour Code: Red

The type of vehicle is a not a clear risk factor for the occurrence of the collisions but it is a clear risk factor for the consequences of the collision. The mass and the shape of the vehicle are crucial for the injury outcomes.

Abstract

The vast majority of pedestrian collisions involved a passenger car.(70% Spain, 81% UK, 76% USA) . In 90% of the accidents involving a passenger car, an SUV or a pick-up the pedestrians were struck by the front of the vehicle.

The literature indicates that an increase in vehicle curb weight is strongly associated with an increase in pedestrian mortality and increasing injury severity. The vehicle mass and the type of vehicle are linked risk factors and in many cases they also linked to speed.
More than 90% of these accidents involved a single vehicle.

4.1.5 Prevalence of pedestrian factors in crash data / Injury level

Colour Code: Red

The scientific community has studied extensively the risk factors which contribute to increase the injury levels of pedestrian involved in a road crash.

Abstract

For both children and adults, fatal injuries are more strongly associated with male pedestrians , darkness, mid-block collision location and lack of traffic control device. For children, wet road conditions are also associated with fatalities and in adults, hit-and-run crashes are associated with fatalities.

An important cause of the high fatality rate of older cyclists and pedestrians is the physical vulnerability of elderly people. Since bones and soft tissue are more brittle and less elastic in this age group, they are at higher risk of severe injury, even if the crash forces are the same

The type of vehicle is a risk factor for sustaining more severe injuries. An increase in mortality is seen compared to conventional passenger cars for SUVs ($P = 0.001$) and Pick-ups ($P = 0.016$), but not for vans ($P = 0.654$). Similarly, being hit by an SUV or Pick-up appeared to result in an overall higher pedestrian ISS score.

When the vehicle speed at impact rises the pedestrian mortality and injury level also increases. Pedestrians hit in speed limit areas of ≤50 kph died 25% of the time, whereas, those hit in areas of 70 kph or greater died more than 40% of the time. Thus the crash severity is higher in rural areas, because generally these collisions occur at higher speeds.

4.1.6 Prevalence of pedestrian factors in crash data / Time of crash

Colour Code: Grey

The time of the crash is a contributory factor for run over accidents. However it varies a lot between countries, seasons, working/leisure days, etc… it is therefore not a clear risk factor

Abstract

Pedestrian collision patterns vary by time of year due to the seasonal changes in sunset time. For example, in the US, in December, collisions are concentrated around twilight and the first hour of darkness throughout the week while, in June, collisions are most heavily concentrated around twilight and the first hours of darkness on Friday and Saturday.

Generally, other known risk factors such as alcohol or drugs use and involvement of young adults are linked to the time of the crash. Although the exact risk of fatal collisions by time of day is unclear (due to lack of exposure data), the relative fatal collision frequencies by time of day indicate when crashes are occurring.

4.1.7 Pedestrian - Vehicle design / Vehicle shape

Colour Code: Yellow

International literature indicates that differences in vehicle shape, particularly when considering taller or more aggressive vehicle such as light vans and sports utility vehicles (SUVs) leads to more severe pedestrian injuries and a higher risk of fatality.

Keywords: Pedestrians, vehicle shape, light trucks, passenger vehicles, SUVs

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the shape of the vehicle. It has been estimated that the effect of being hit by a more 'aggressive' vehicle relates to a 3 fold increase in fatality risk, in other words being hit by a light truck/pickup can result in a significantly higher fatality risk than being hit by a standard passenger car. In addition, although to a lesser degree than fatalities, there is evidence of increased injury risk for light trucks, motorcycles and SUV vehicle shapes. Most research has been conducted in the USA where the vehicle fleet features proportionally more 'aggressive' vehicles, however recent fleet changes in the EU make the result for more relevant.

4.1.8 Pedestrian - Visibility / Conspicuity

Colour Code: Grey

Some studies have investigated the association between pedestrians' increased risk at night with their lack of sufficient conspicuity and their failure to appreciate the magnitude of drivers' difficulty seeing them at night.

Abstract

A small number of studies investigated pedestrian conspicuity as a contributory factor in run over accidents. There is no clear evidence that conspicuity is a risk factor on its own, however it appears linked to the lighting conditions, especially at dusk, dawn and in darkness.

4.1.9 Low NCAP rating

Colour Code: Yellow

International literature indicates that in a collision between a pedestrian and a low scoring pedestrian NCAP vehicle there exists a significantly increased risk of more severe pedestrian injuries and an overall poorer long term injury outcomes compared to high performing EuroNCAP cars.

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the passive crash performance of the vehicle in a collision. This passive performance can be measured and compared by using the European new car assessment program (EuroNCAP) score. By comparing injury outcomes from real world collision data and the EuroNCAP score of the striking vehicle it has been estimated that the effect of being hit by a vehicle which scores just one point more than a comparative vehicle through the EuroNCAP pedestrian testing regime relates to a 1% decrease in risk of serious injury. This rises to 2.5% decrease in risk of fatality per additional EuroNCAP point.

The most important point to emphasise with this topic is that there is currently a significant limitation to the analysis as the very best performing vehicles as tested by EuroNCAP feature less commonly in the general vehicle fleet. This effect is only seen with the very latest vehicles with potentially the highest pedestrian test scores as there will be latency in the system between a particular vehicles NCAP assessment and being seen in sufficient numbers on the roads to feature in collision data. Potential issues may occur when drawing conclusions on this type of vehicle as the collision statistics do not support robust conclusions. In addition the effect of high impact speeds (>50kph) are less well understood as this is above the limits of current testing (currently 40kph for head and upper and lower leg impact tests). As such pedestrian kinematics, Impact locations and crush pattern are likely to be different to that seen in testing and possibly beyond the performance limits of vehicles designed to meet testing limits.

In addition it is important to understand how EuroNCAP scores are derived. Scores awarded to vehicles are not directly comparable between different vehicles or over time. For example a vehicle that scored 5 EuroNCAP stars will only be broadly comparable between its direct competitors and will not be comparable to vehicles manufactured earlier or later that also score 5 stars. The main reason for this is that the NCAP tests evolve to include more stringent requirements; vehicles tested five years ago, despite scoring 5 stars in period, are not comparable with 5 star vehicles tested today as the threshold for scoring has changed. The studies included cover data collections periods between 4 and 14 years (all between 2003 and 2014) so the effect of evolving testing protocols may be evident.

Although not affecting the pedestrians testing to the same degree, the test protocol in full scale crash testing results in vehicles that are only measured against themselves, in effect this result in a crash test vehicle hitting itself in frontal and side impacts. This test design means that a vehicle's 5 star score is only comparable with other vehicles in its group. (Supermini vs supermini as opposed to supermini vs large family car).

4.2 RISK FACTOR RELATED TO CYCLISTS

From the CARE database (year 2014) the proportion of Bicyclists represents approximatively 8% of the overall fatalities in the EU28 (figure below).

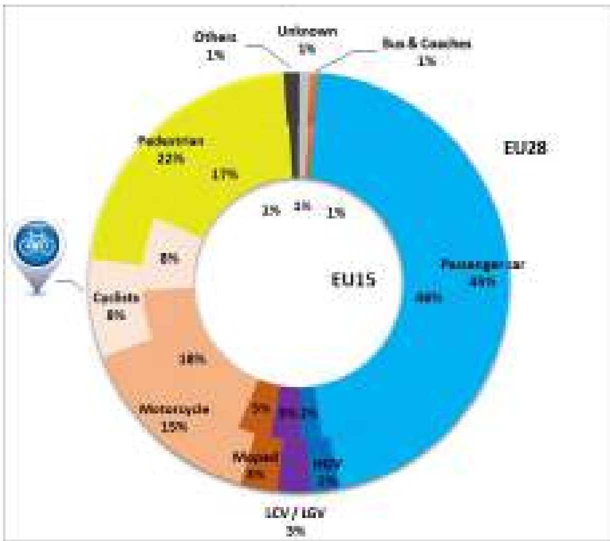


Figure 8 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

Among the European states, the Netherlands, Denmark and Slovenia have the highest rate of fatalities (respectively with 24%, 17% and 13% of the overall fatalities of the country).

Figure 9 : Proportion of Bicyclist fatalities according to European countries (source CARE, year 2014)

4.2.1 SafetyCube scenarios dedicated to Cyclists

We consider here all injury accident involving at least one cyclist. The following figures are based on the French data for the year 2011. For the injury accidents involving at least one cyclist, we can see that the bicycle is predominantly in collisions with a passenger car (75%) or a PTW (13%). If we look at the fatalities only, 66% are caused by a passenger car and 21% by a truck.

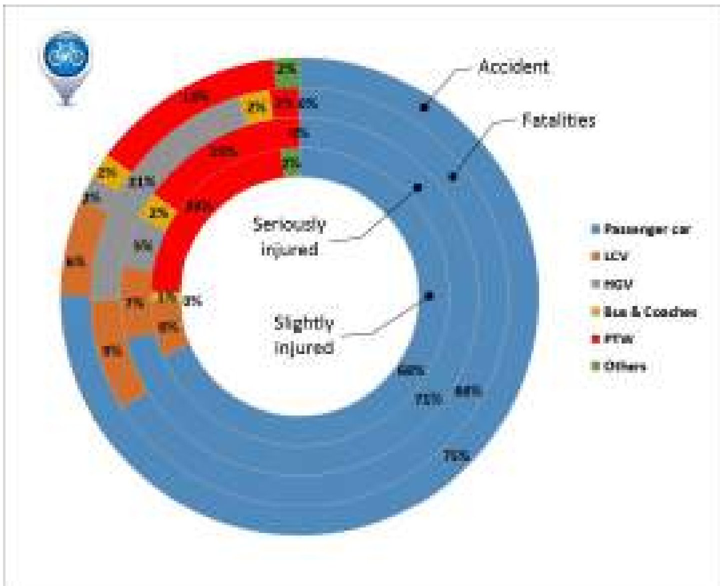


Figure 10 : Distribution of cyclist accidents severity according to the type of road users involved (source VOIESUR, France 2011)

If we look at the distribution of the bicyclist injuries according to the body region in Figure 11 below, AIS3+ injuries (in red) are more frequent for the head (30%) the lower extremities (26%) and the thorax (21%). For the AIS2+ injury level (in orange) the three most frequently injured body regions are lower extremities (26%), the upper extremities (23%) and the head (21%).

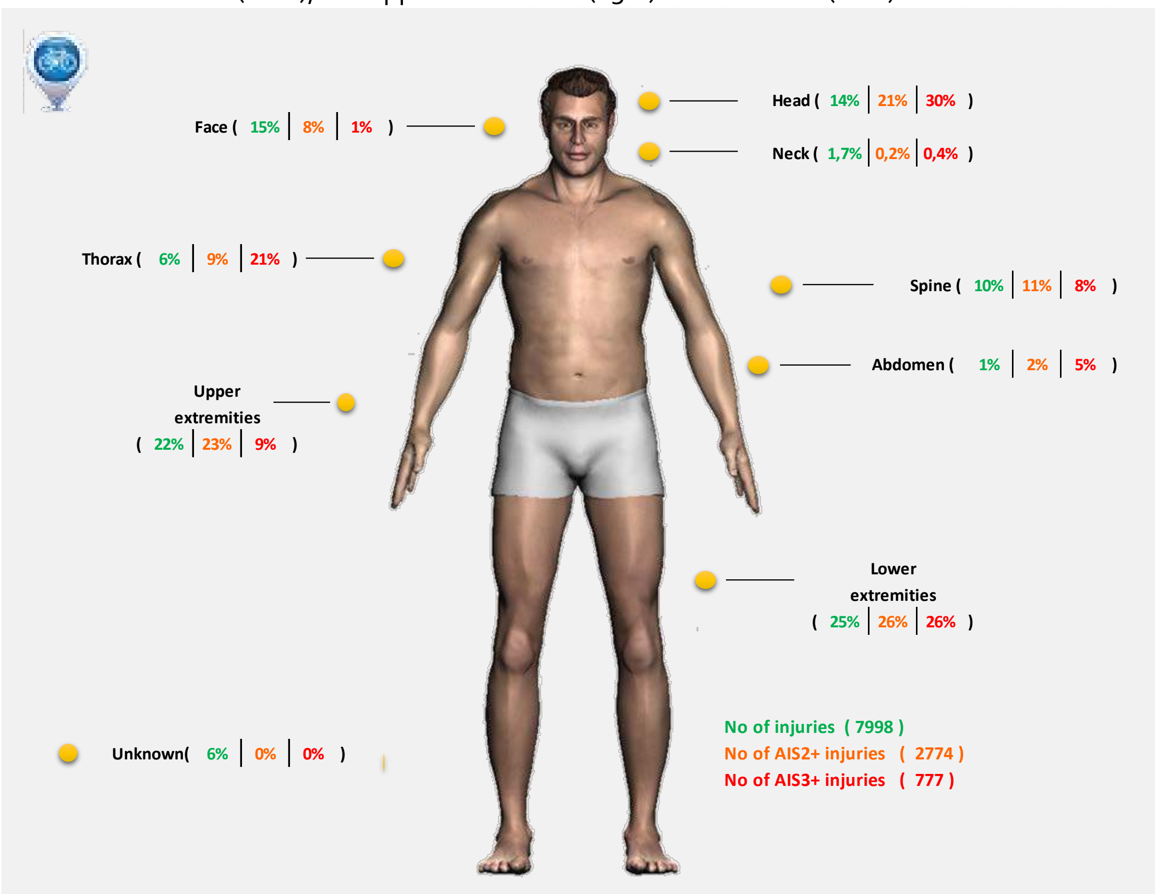


Figure 11 : Cyclist: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

For this category of vehicle, the most frequent scenarios (if we except the category "others (Re)"), are "Crossing configuration, Cyclist coming from farside (C1)" (20%), followed by "Crossing configurations, Cyclist coming from nearside (C2)" (15%) and "Same direction, cyclist ahead (L1)" (10%).

The most deadly scenarios is "Same direction, cyclist ahead (L1)" (36%) followed by "Crossing configurations, Cyclist coming from nearside (C2)" (17%) and "Crossing configuration, Cyclist coming from farside (C1)" (9%).

The most severe accidents (number of KSI per 100 involved vehicles) are "Same direction, cyclist ahead (L1)" (51 KSI) followed by "same direction, cyclist ahead and changing lane (L2)" (45 KSI) and "cyclist coming (nearside) farside, vehicle turning (nearside) farside (T4)" (39 KSI).

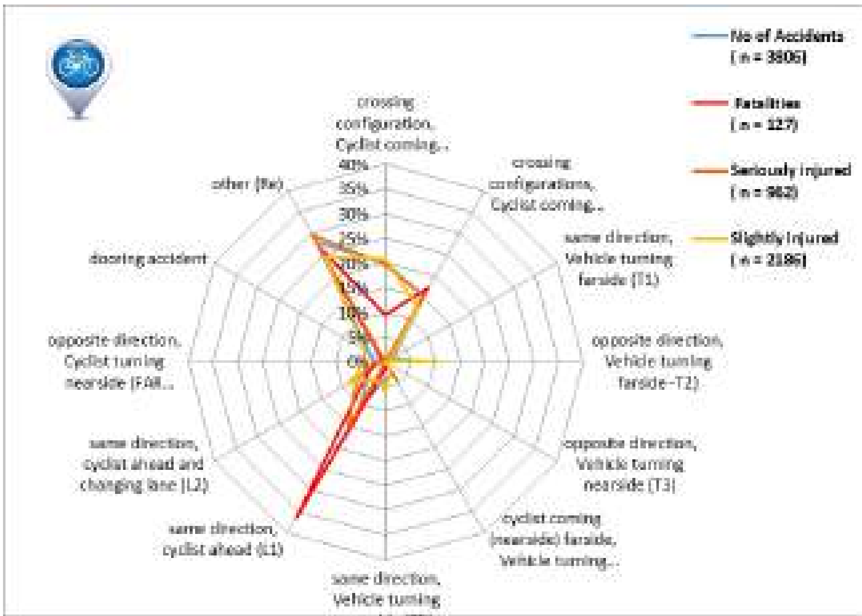


Figure 12 : Distribution of cyclist accidents scenarios according to their severity
(source VOIESUR, France 2011)

France 2011	Scenario no.	No of Accidents	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)
crossing configuration, Cyclist coming from farside (C1)	2.1	766	12	189	457	201	26
crossing configurations, Cyclist coming from nearside (C2)	2.2	581	22	148	281	170	29
same direction, Vehicle turning farside (T1)	2.3	66	0	0	22	0	0
opposite direction, Vehicle turning farside -T2)	2.4	303	3	64	235	67	22
opposite direction, Vehicle turning nearside (T3)	2.5	0	0	0	0	0	0
cyclist coming (nearside) farside, Vehicle turning (nearside) farside (T4)	2.6	108	0	42	44	42	39
same direction, Vehicle turning nearside (T5)	2.7	133	2	0	131	2	2
same direction, cyclist ahead (L1)	2.8	383	46	148	89	194	51
same direction, cyclist ahead and changing lane (L2)	2.9	155	5	64	192	69	45
opposite direction, Cyclist turning nearside (FAR SIDE) (On)	2.10	89	2	22	87	24	27
dooring accident	2.11	154	1	0	109	1	1
other (Re)	2.12	1068	34	285	539	319	30
	Total	***3806***	***127***	***962***	***2186***	***1089***	***29***

Table 11 : Accident characteristics according to the cyclist scenarios
(Source VOIESUR, France 2011)

4.2.2 Prevalence of cyclists factors in crash data / accident characteristics

Colour Code: Red

In depth accident data shows that cyclists have an approximately equal share of participation in injury crashes and account for about 15% of the accident participants (according to GIDAS). Being vulnerable road users, cyclists are often injured in these collisions and have a higher rate of severe injuries compared to car occupants. It is expected that increased participation in cycling, especially the use of e-bikes, is expected to impact collisions statistics in the near future.

Abstract

Being vulnerable road users cyclists are often injured when involved an crash. According to in-depth accident data, around 15% of the participants in injury accidents are cyclists and in these collisions they are the injured participants in over 90% of the cases.. Most accidents with cyclists occur inside city limits thus accidents with cyclists have prevalence at crossings and junctions. According to in-depth accident data (GIDAS) more than half of the collision opponents in cyclists collisions are cars. However when cyclists have an accident with another road user cyclists are mostly found not to be the 'at fault' party in the collision.

4.2.3 Prevalence of cyclists factors in crash data / Injury severity

Colour Code: Red

In depth accident data shows that cyclists have an approximately equal share of participation in injury crashes and account for about 15% of the accident participants (according to GIDAS). Being vulnerable road users, cyclists are often injured in these collisions and have a higher rate of severe injuries compared to car occupants. It is expected that increased participation in cycling, especially the use of e-bikes, is expected to impact collisions statistics in the near future.
.Literature on the injuries of cyclists often focuses on the helmet use and is sufficiently available.

Abstract

Being vulnerable road users cyclist are often injured when involved in a collisions. According to in-depth accident data about 15% of the participants in injury accidents are cyclists, cyclists remain uninjured in only about 8% of cases. Although around ¾ of cyclists involved in injury accidents only suffer slight injuries, around 14% of cyclists have more serious injuries. When involved in an accident a cyclist often suffers two collisions: a primary collision when colliding with the opponent or object and a secondary collision when falling to the ground. This results in nearly 60% of cyclists having injuries on their legs, nearly half of the cyclists have injuries on the arms and over 30% sustaining from head injuries. It is proven than a reduction of head injuries, particularly serious head injuries can be achieved by using a bicycle helmet.

4.2.4 Cyclist - Visibility / Conspicuity

Colour Code: Yellow

In depth accident data shows that cyclists have an approximately equal share of participation in injury crashes and account for about 15% of the accident participants (according to GIDAS).For cyclists, visibility and conspicuity play an important role in the accident events. It is expected that increased participation in cycling, especially the use of e-bikes, is expected to impact collisions statistics in the near future. Literature on bicycle lighting is not available in high numbers.

Abstract

Being vulnerable road users cyclist are often injured when involved an accident. Visibility and Conspicuity are important factors for cyclists. Aroud 10% of accidents involving cyclists occur during

night time and approximately 7% during twilight according to the German in-depth accident study GIDAS. Because cyclists are vulnerable to having an accidents when there are slight road surface deficiencies visibility plays an important role. On the other hand cyclists are easily overlooked by other road users due to their slim silhouette. For example in Germany during twilight about two thirds of the cyclists involved in an accident did not have light or did not use their light and during night time about half of the cyclists did not have light or did not use their light. In about 75% of cases street lighting was available during night time.

4.3 RISK FACTORS RELATED TO POWERED TWO WHEELERS (PTW) OR ALL-TERRAIN VEHICLE (ATV)

The category PTW gathers mopeds, scooters, motorcycles, side-cars and other three wheelers vehicles such as Piaggio MP3, Can-Am Spider etc..

PTW use represented more than 33 million vehicles in Europe in 2014. Only 29% of these vehicles were mopeds.

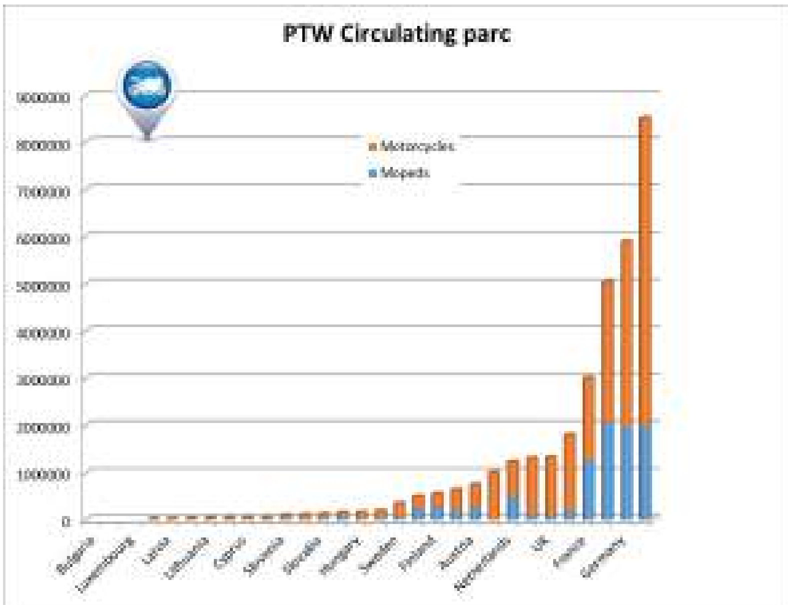


Figure 13 : Powered Two Wheelers in use in Europe (source ACEM)

From the CARE database (year 2014) the proportion of PTW occupants (motorcycles and moped) represents approximatively 18% (15% for motorcycle and 3% of moped) of the overall fatalities in EU28 (figure below).

The rate of killed occupants is 2.7 time higher than for passenger car occupants.

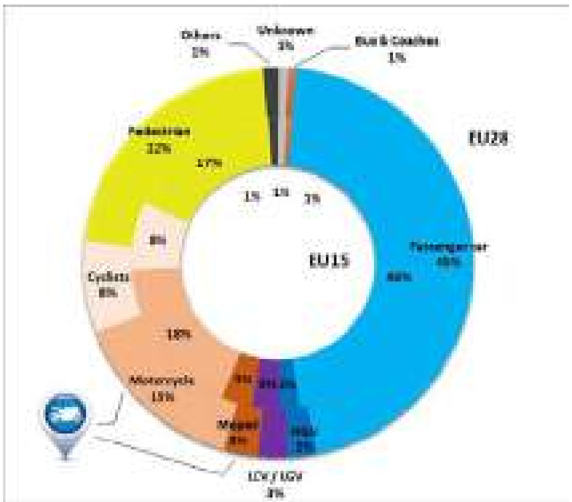


Figure 14 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

Among the European states, Greece, Cyprus, Italy and France have the highest rate of fatalities (respectively with 34%, 29%, 25% and 25% of the overall fatalities of the country).

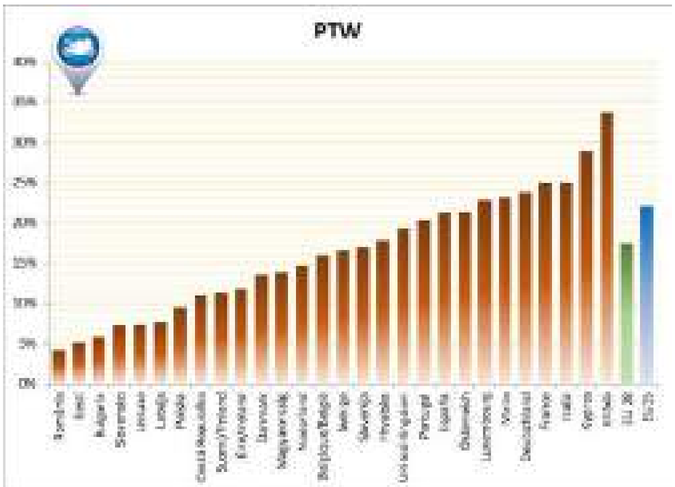


Figure 15 : Proportion of PTW occupant fatalities according to European countries (source CARE, year 2014)

If we look at severity according to the type of impact, we can see in France (2014) that "frontal impact" is the crash the most represented (73% of fatalities), followed by "side impact" (13%) and "other impact" (9%) (which includes single vehicle PTW accidents)

Although the frontal impact is the most frequent collision for PTWs, we can see in the following table that overturn is the most severe impact (52 killed or severely injured occupants for 100 vehicle involved).

France 2014	No of vehicles	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 veh.)
Frontal impact	14070	573	5596	7861	6169	44
Side Impact	4180	102	1457	2790	1559	37
Rear Impact	1387	24	320	981	344	25
Rollover or overturn	256	22	111	132	133	52
Others impact	2140	69	673	1414	742	35
Total	***22033***	***790***	***8157***	***13178***	***8947***	***41***

Table 12 : Distribution of the PTW occupants according to the severity and the type of impact (Source BAAC, France 2014)

4.3.1 SafetyCube scenarios dedicated to PTW

We consider here all injury accident involving at least one PTW.

If we look at the distribution of the PTW occupant injuries according to the body region, AIS3+ injuries (in red) are more frequent for the lower extremities (32%), the upper extremities (21%) and the head (20%). For the AIS2+ injury level (in orange) the three most frequently injured body regions are the lower extremities (34%), the upper extremities (29%) and the head (12%).

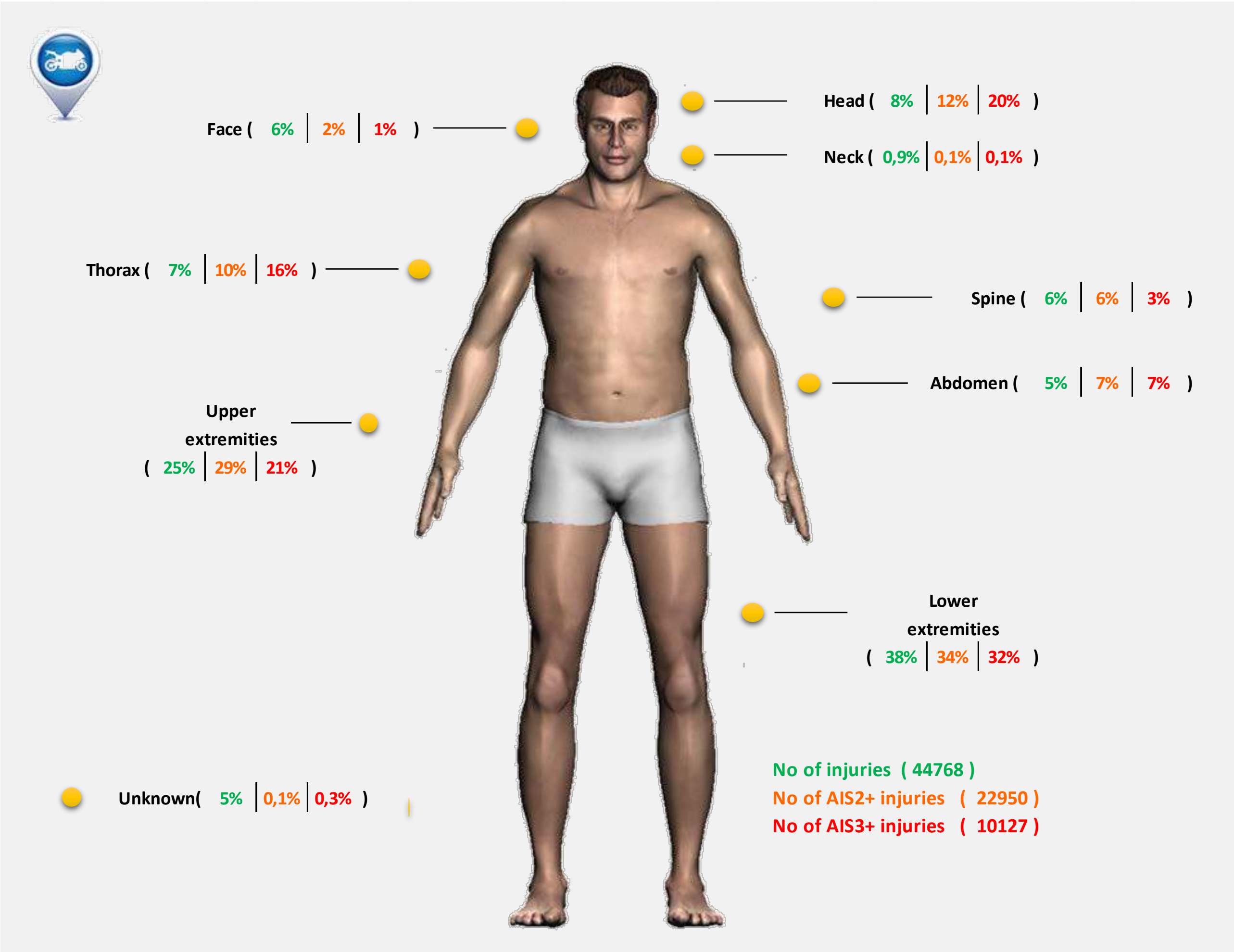


Figure 16 : PTW occupant: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

In France in 2011 (source VOIESUR), we count a total of 24,475 injury accidents involving 25,338 vehicles. For this category of vehicle, the most frequent scenarios are "Rear-end collision or same direction traffic" (26%), followed by "junction accident (turning)" (21%) and "Single vehicle accident (on roadway)" (12%).

The most deadly scenarios are "Head-on collisions or on coming traffic" (24%) followed by "Single vehicle accident (run-off road)" (22%) and "Junction accident (turning)" (17%).

The most severe accidents (number of KSI per 100 involved vehicles) are "Single vehicle accident (run-off road)" (79 KSI) followed by "Head-on collisions or on coming traffic" (62 KSI) and "Railway level crossing (44 KSI).

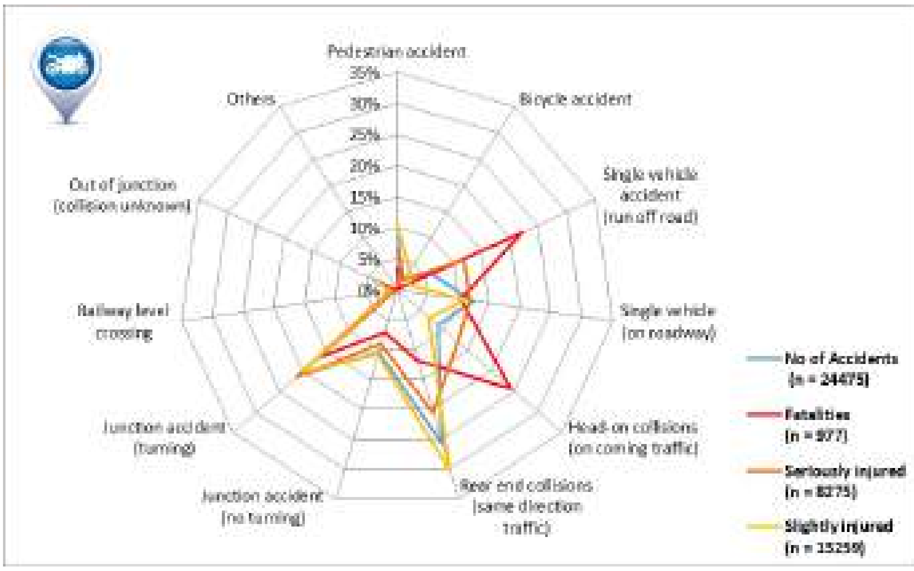


Figure 17 : Distribution of the PTW accidents scenarios according to the severity
(Source VOIESUR, France 2011)

France 2011	No of Accidents	No of PTW	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)	KSI (for 100 veh.)
Pedestrian accident	2046	2070	35	546	1405	581	28	28
Bicycle accident	499	499	3	148	493	151	30	30
Single vehicle accident - Run off road	1516	1516	217	974	277	1191	79	79
Single vehicle - on roadway	3043	3043	102	992	1491	1094	36	36
Head-on collisions / on coming traffic	2126	2221	237	1075	906	1312	62	59
Rear end collisions / same direction traffic	6299	6711	115	1696	3994	1811	29	27
Junction accident – no turning	2551	2740	69	742	1432	811	32	30
Junction accident – turning	5193	5264	162	1763	2652	1925	37	37
Railway level crossing	204	204	3	86	92	89	44	44
Out of junction - Collision unknown	998	1070	34	252	517	286	29	27
Others								
Total	***24475***	***25338***	***977***	***8275***	***13259***	***9252***	***38***	***37***

Table 13 : Accident characteristics according to the PTW scenarios
(Souce VOIESUR, France 2011)

4.3.2 Prevalence factors in crash characteristics

Colour Code: Grey

International literature indicates that there is a diverse range of risks presented to powered two wheeler users when using the public highway. In general the topic of powered two wheelers is not as widely studied as that of passenger vehicle occupants or vulnerable road users limiting transferability and generalizability This topic covers a range of studies which have be coded to illustrate a range of risks presented to powered two wheeler users.

Abstract

Powered two wheeler accident characteristics encapsulate a range of different features which have been documented through real world crash data for accidents involving PTWs. Compared to

passenger vehicles there are comparatively few in depth studies investigating the features of PTW crashes and fewer still that study the same features, this poses problems with identifying characteristics that do exist in PTW collisions and makes it necessary to consider a diverse range of PTW crash studies together as one topic, the benefit of this approach will be to reveal where PTW users are exposed to a greater risk of injury or mortality. It was found that overall and within this wide range of topics that young PTW users and those with limited experience of a particular PTW are at increases risk of injury or death, additionally greater engine size and travel speeds over the posted speed limit also increase the risks to PTW users. The effect of PTW use on vulnerable groups such as pedestrians was also covered showing that PTWs are at a higher risk of hitting pedestrians than 4 wheeled vehicles. The approach of combining varied studies into one synopsis presents difficulties for statistical power, generalizability and transferability as there will be a limited amount of information about each individual characteristic.

4.3.3 Prevalence factors in crash data / Vehicle characteristics

Colour Code: Grey

The review of international literature indicates that vehicle characteristics that might have an impact as a risk factor are motor displacement and motorcycle type. These characteristics are almost always linked to rider behaviour and risk taking and should not be considered as risk factors on their own.

Abstract

An increase in the motorcycle engine size may increase the injury severity level of a rider involved in a collision regardless of the control measure adopted. Studies report a distinct relationship between engine displacement (cubic capacity) and susceptibility to wobbling (unrestricted oscillation of front wheel flutter and high-speed weave). Collisions with heavier vehicles result in more severe injuries. In many studies, motorcycle type does not usually appear as a risk factor, however in a Norwegian study sport bikes appear to have a higher risk of suffering an accident.

4.3.4 Prevalence factors in crash data / Impact characteristics

Colour Code: Red

Within this category there are results in the literature review that confirm that the accident type, the partner involved in the accident, the motorcycle speed, alcohol involvement and the road alignment are risk factors for PTW accidents.

Abstract

Alcohol impairment and speeding are significant factors determining the severity outcomes of motorcycle involved crashes. A range of studies find that the severity of crashes tends to increase with right-angle crashes and left-turn-across-path crashes, which tend to occur at intersections. Single vehicle accidents which result in collisions with fixed objects, run-off road, overturn/rollover and rear end collisions increased the risk of PTW riders or pillions of sustaining serious injuries.

When a PTW and a truck or SUV are involved in a collisions the PTW user has an increased risk of sustaining a MAIS3+ injury.

4.3.5 Prevalence factors in crash data / Injury severity

Colour Code: Red

Rider age increases the probability of sustaining an injury and increase the likely injury level.

Abstract

Increasing numbers of older motorcyclists are taking to the road as the population ages. The literature review shows that these riders are at an increased risk for higher injury severity and higher number of injuries. In addition these riders are also at an increased risk of longer and more complex periods of hospitalization and higher care demands after discharge compared with younger riders.

Geriatric consultation or implementation of advanced-age treatment protocols may address factors leading to increased hospital stays and complications. Patient and provider awareness of the increased post-discharge needs and future risks of injured older riders may provide an opportunity for increased engagement in rehabilitation, therapies, and nutrition. The predicted persistent growth in the advanced-age demographic in developed countries through to 2050 suggests that care systems will need to evolve to provide more resources for hospital and post-discharge needs for older trauma patients.

4.3.6 Protective equipment design / Poor helmet performance

Colour Code: Yellow

Poor helmet performance and riders who wear open-face helmets have a higher risk of sustaining facial and head injuries. The type of helmet and the helmet fixation are key risk factors in sustaining injuries in PTW accidents.

Abstract

The literature review showed that helmet protectiveness was directly related to the area of coverage. This indicates that the larger coverage, the more effective the helmet. Many researchers unanimously agreed that the full-face helmet was the most effective in comparison with other helmet types. Its effectiveness is attributed to its design which consists of full head coverage and a chin piece which extends to cover the entire mandible and part of the face making it more resistant to ejection. Full face helmets have also been proven to increase the effectiveness of helmet fixation, reducing head and brain injuries.

4.3.7 Protective equipment design / other equipment

Colour Code: Grey

Little empirical evidence on the effectiveness of other protection devices such as motorcycle airbag jackets and back and leg protectors is available.

Abstract

One study (2009), reviewed previous studies on protective clothing and concluded that no advantage in the occurrence of fractures were associated to protective clothing, except for reduced soft tissue injuries. This study concluded that limited empirical evidence on the effect of protective boots, jackets, leg protectors, etc., to PTW safety is available in the literature. However later studies (2011 & 2014) found strong associations between use of protective clothing and mitigation of the consequences of injuries. Given this evidence it seems likely that the use of protective clothing will confer significant benefits to riders in the event of a crash.

4.3.8 Technical defects or maintenance / Faulty headlights or taillights

Colour Code: Grey

No evidence of faulty headlights or tail lights contributing to accidents.

Abstract

Technical failure or poor maintenance is present as a contributory factor in 3%-8% of PTW accidents. Around 10% of the motorcycles were in a poor condition before the crash.

Table 14 MAIDS. Specific cause of PTW vehicle failure, accident cause related problem

	Frequency	Percent
Tyre or wheel problem	34	3,7
Brake problem	11	1,2
Steering problem	1	0,1
Suspension problem	1	0,1
Not applicable, no PTW vehicle failure	866	94
Unknown	8	0,9
Total	921	100

Another study indicates that broken lights were present in less than 3% of the PTW crashes.

4.3.9 Technical defects or maintenance / Tyres

Colour Code: Grey

Tyre defects do not appear to be a significant risk in PTW accidents, However, incorrect or inappropriate motorcycle tyre pressure were found in more than 60% of the accidents. There is however little literature review concerning tyres problems with PTWs

Abstract

According to MAIDS, in 3.7% of motorcycle accidents the tyres or wheel contribute to the accident. However, other studies indicate that only one third of the motorcycles involved in an accident had the correct tyre pressure before the crash. Unfortunately there are only a few studies assessing the mechanical failures as risk factor for PTW accidents making assessments of statistical power, generalizability and transferability problematic.

4.3.10 Technical defects or maintenance / Faulty steering system or suspension

Colour Code: Grey

No evidence of faulty steering system or suspension contributing to accidents.

Abstract

According to collisions data, less than 1% of PTW accidents include evidence that there were steering problems before the crash or contributing to the accident

4.3.11 Technical defects or maintenance / Faulty brakes

Colour Code: Grey

There is no evidence that faulty brakes are a risk factor in PTW accidents.

Abstract

According to collision data around 1% of motorcycle accidents have faulty brakes as contributing factor.

4.4 RISK FACTORS RELATED TO PASSENGER CAR

The passenger car vehicle fleet represented more than 907 million vehicles worldwide in 2014. In Europe this fleet counts about 252.694 million vehicles (120.984 in the US). This fleet is 6.5 times higher than the LCV/LGV one (source ACEA).

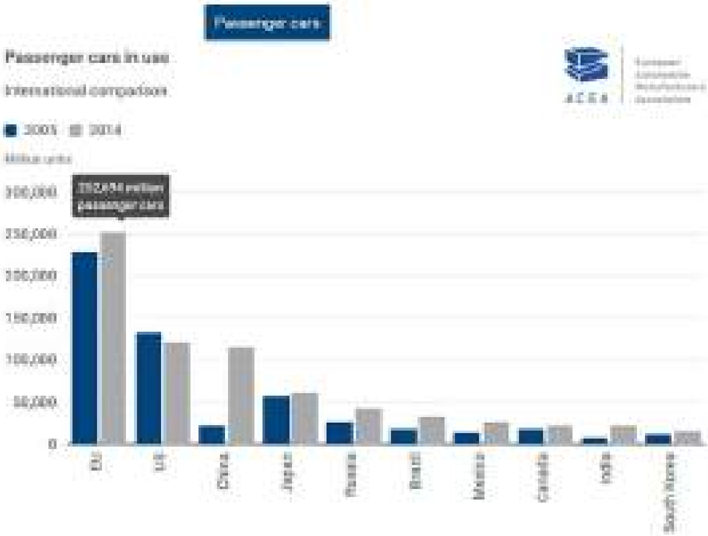


Figure 18 : Passenger car in use in the world (source ACEA)

From the CARE database (year 2014) the proportion of passenger car occupants represents approximatively 45% of the overall fatalities in EU (figure below).

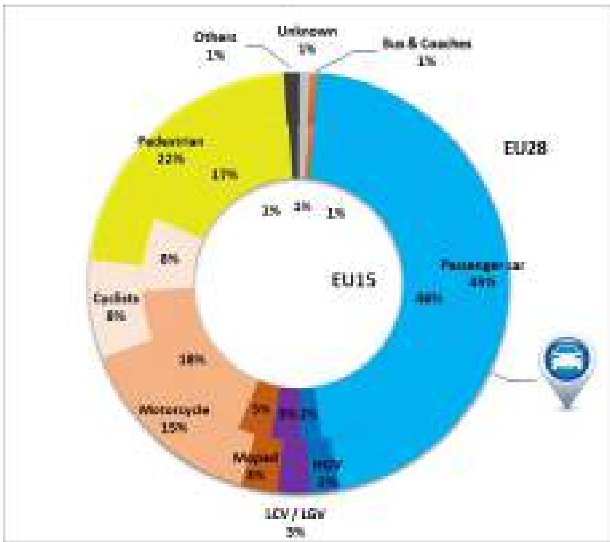


Figure 19 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

This rate is the highest among all categories of road users. However, the number of persons killed decreases year after year in most of the European countries. As an example, in France, this rate (all fatalities included) was about 62% in year 2000 and is around 52% in 2015.

Among the European states, Malta, Luxembourg and Bulgaria have the highest rate of fatalities (respectively with 69%, 68.6% and 63% of the overall fatalities of the country).

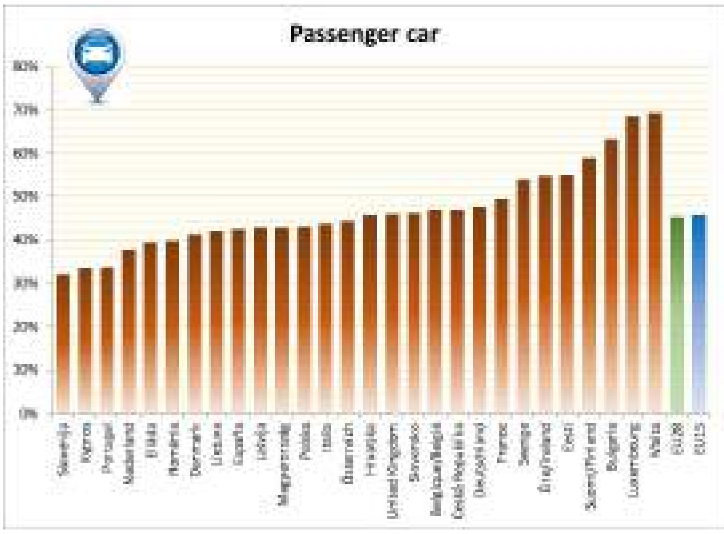


Figure 20 : Proportion of passenger car occupant fatalities according to European countries (source CARE, year 2014)

If we look at severity according to the type of impact, we can see in France that frontal impact is the crash the most represented (65% of fatalities), followed by side impact (20%) and rollover impact (7%).

However, although frontal impact is the most frequent collision for passenger cars, we can see in the following table that rollover is the most severe impact (60 killed or severely injured occupants per 100 vehicle involved).

France 2014	No of vehicles	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 veh.)
Frontal impact	37310	1075	7915	12136	8990	24
Side Impact	6837	337	1138	2189	1475	22
Rear Impact	11468	93	1110	5408	1203	10
Rollover or overturn	1154	109	588	771	697	60
Others impact	2547	49	395	804	444	17
Total	***59316***	***1663***	***11146***	***21308***	***12809***	***22***

Table 15 : Distribution of the passenger car occupants according to the severity and the type of impact (Souce BAAC, France 2014)

4.4.1 SafetyCube scenarios dedicated to Passenger Cars

We consider here all injury accident involving at least one Passenger car.

If we look at the distribution of the Passenger car occupant injuries according to the body region, AIS3+ injuries (in red) are more frequent for the thorax (26%), the head (21%) and lower extremities (20%). For the AIS2+ injury level (in orange) the top 3 of the most frequently body region injured are lower extremities (20%), the upper extremities (20%) and the thorax (18%).

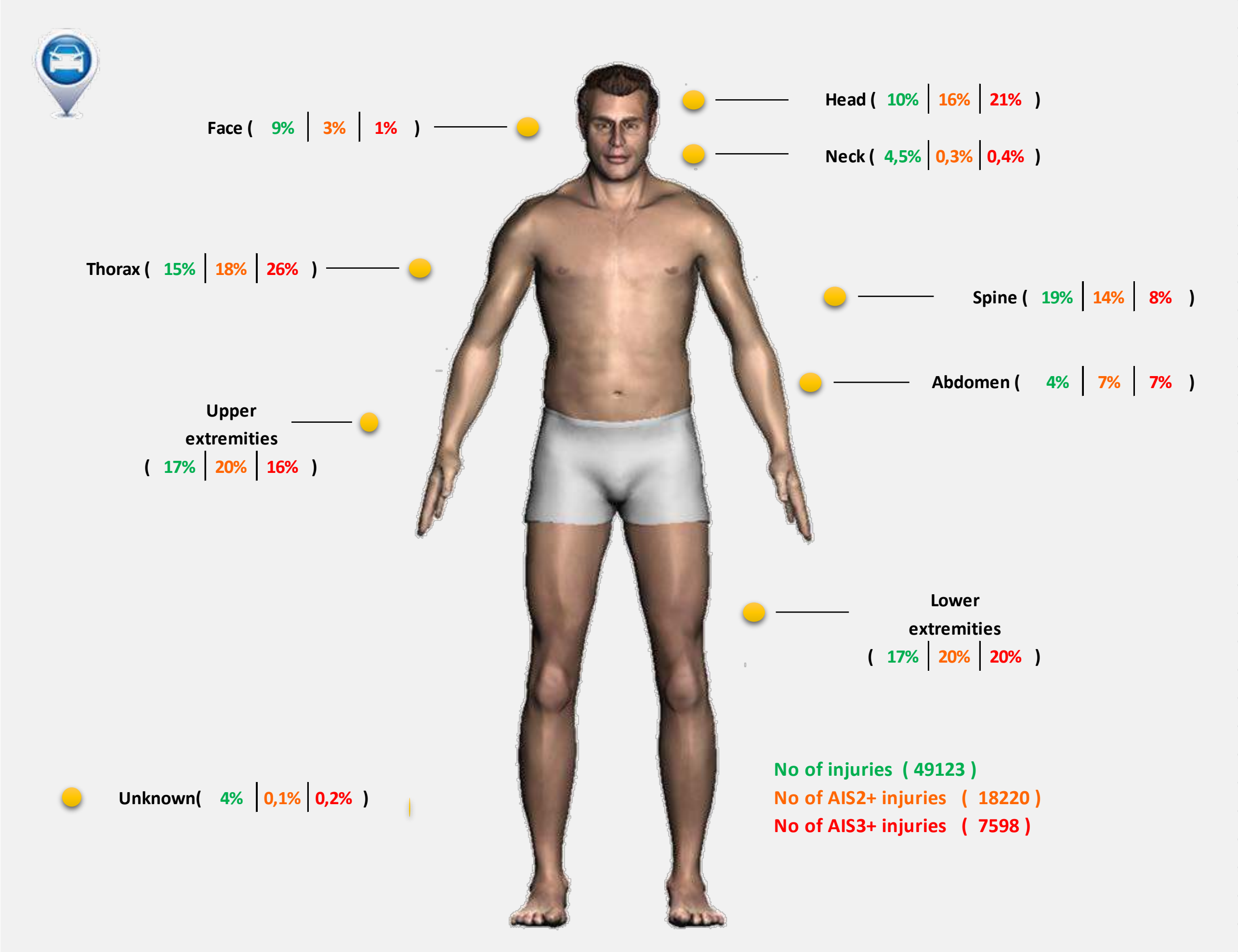


Figure 21 : Passenger car occupant: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

In France in 2011 (source VOIESUR), we count a total of 46,027 injury accidents involving 59,544 vehicles. For this category of vehicle, the most frequent scenarios are "Rear-end collision or same direction traffic" (21%), followed by "Pedestrian accident" (17%) and "junction accident (turning)" (15%).

The most deadly scenarios are "Single vehicle accident (run-off road)" (30%) followed by "Head-on collisions or on coming traffic" (28%) and "Pedestrian accident" (11%).

The most severe accidents (number of KSI per 100 involved vehicles) are "Head-on collisions or on coming traffic" (83 KSI) followed by "Single vehicle accident – run-off road" (76 KSI) and "Railway level crossing (72 KSI).

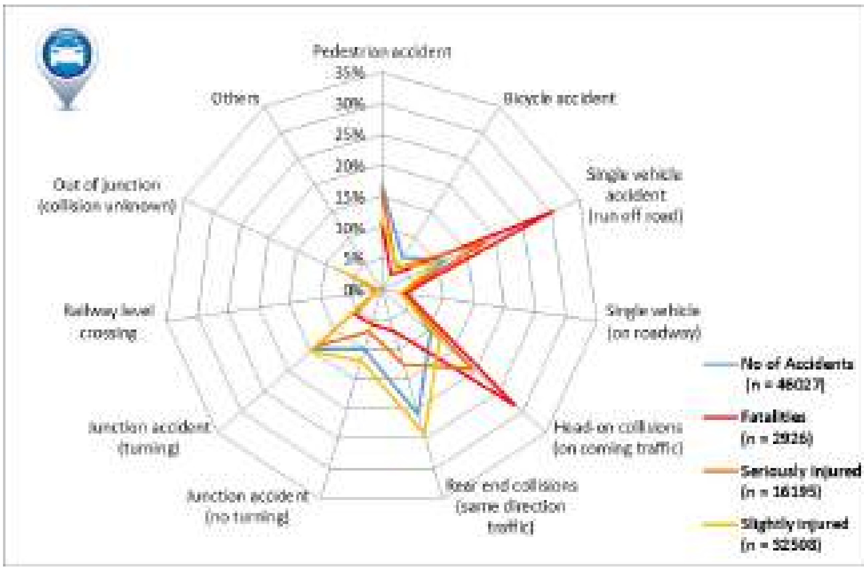


Figure 22 : Distribution of the Passenger Car accidents scenarios according to the severity (Source VOIESUR, France 2011)

France 2011	No of Accidents	No of PC	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)	KSI (for 100 Veh.)
Pedestrian accident	7765	7961	313	2564	3631	2877	37	36
Bicycle accident	2858	2946	84	690	1497	774	27	26
Single vehicle accident (run off road)	5136	5136	882	3008	3086	3890	76	76
Single vehicle (on roadway)	1729	1729	114	533	979	647	37	37
Head-on collisions (on coming traffic)	4797	7146	828	3130	4004	3958	83	55
Rear end collisions (same direction traffic)	9628	14052	203	2027	7876	2230	23	16
Junction accident (no turning)	4553	6469	171	1119	3837	1290	28	20
Junction accident (turning)	6748	8438	169	2236	4940	2405	36	29
Railway level crossing	225	270	18	144	87	162	72	60
Out of junction (collision unknown)	2589	5397	144	745	2571	889	34	16
Others	0	0	0	0	0	0	0	0
Total	***46027***	***59544***	***2926***	***16195***	***32508***	***19121***	***42***	***32***

Table 16 : Accident characteristics according to the Passenger Car scenarios (Source VOIESUR, France 2011)

4.4.2 Prevalence of vehicle factors in the crash data

Colour Code: Yellow

Passenger cars remain the most popular mode of transport in high income countries and their occupants represent the most sizeable fatality population compared to other types of road users. Despite a gradual decrease in the mortality of Passenger car occupants since 2004 (mainly thanks to the progress of the safety of vehicles but not only), this population remains high risk, particularly in single vehicle accident configurations.

Abstract

Passenger car accidents represent a big issue for road safety. With the exception of some countries in South-East Asia and the Western Pacific regions, car occupants have the most significant fatality rate compared to other road user groups. In Europe in 2014 car occupants represent more than 45% of the overall fatalities.

Risks factors associated with passenger cars are numerous but some of them appear to have a higher contribution. From human behaviour factors it is possible to identify driving speed, alcohol, fatigue and age of the driver (young and elder). In terms of environmental factors (infrastructure included), darkness (1/3 of fatalities), rural roads (more than 50% of deaths) and intersections (45% of accidents and 21% of fatalities) are shown to be more risky factors. When considering accident configuration, crashes involving a vulnerable road user are significant, however single vehicle crashes and car against heavy vehicle crashes are the most risky situations compared to car to car accidents. For an impact point of view, more than 50% of the fatalities occur in a frontal impact, and 40% in side-impact.

For belted car occupants, the risk of sustaining a severe injury for rear occupants is higher than for front occupants especially in frontal impacts.

Regarding injuries according to the body region for belted car occupants, the thorax is the most frequently injured region; this is followed by the abdomen and lower extremities.

4.4.3 Injury mechanism / Risk to be injured in frontal impact

Colour Code: Red

The bibliographic review on frontal impacts suggests that this type of impact can be given the colour code **red** (risky). This colour code comes from the fact that frontal impacts are not the most dangerous types of impacts, but are by far the most common types of impacts thus resulting in big numbers of severe and fatal injuries.

Abstract

Frontal impacts are those occurring to the front-end of a vehicle and generally defined by the principal direction of force (PDOF) between 11 and 1 o'clock or by the principal area of damage as being the front of the vehicle. Many vehicle factors can influence the outcome of a frontal impact just like the position of the occupant in the vehicle (driver, front passenger, rear left passenger ...), vehicle safety equipment (seatbelts, airbags...), and aggressiveness or protection capacity of different vehicle interior components .

This document is a review of frontal impact risk factors. A systematic literature search has been conducted and relevant studies have been analysed. These studies were very diverse in their nature (different samples, different exposures and outcomes) and a bibliographic review has been achieved in order to outline important conclusions. Results show that frontal impacts are more risky than rear impacts but less risky than side impacts. In frontal impacts, front passengers and rear passengers have almost the same chance of getting fatally injured. Unbelted rear passengers may increase the risks of driver fatality, especially in severe crashes. Airbag deployment reduces the risk of injury especially when combined with seatbelt use. Seatbelts were found to reduce the risks of severe brain injury for full frontal and offset frontal impacts. Second generation, depowered airbags increase injury risk for the thoracic region and decrease injury risk for the upper extremity region when compared with first generation airbags.

4.4.4 Injury mechanism / Risk to be injured in rear impact

Colour Code: Yellow

The bibliographic review on side impacts suggests that this type of impact can be given the colour code **yellow** (probably risky). All studies agree that this type of impact accounts for the lowest numbers of severe or fatal injuries compared to other crash configurations and also generates the lowest risks for car occupants. Nevertheless, one should be mindful of rear passengers because they have a relatively high risk of sustaining severe and fatal injuries in rear impacts combined with an additional risk due to the potential for the number of rear passengers to increase through the increase in carpooling habits.

Abstract

Rear impacts are impacts occurring to the rear end of a vehicle and generally defined by the principal direction of forces (PDOF) between 5, and 7 'o'clock or by the principal area of damage being defined as 'rear' of the vehicle. Many factors may influence the outcome of a rear impact such as the position of the occupant in the vehicle (driver, front passenger, rear passenger), the deformation of the front seat, or contact between the occupants and vehicle interior components.

A review on rear impacts has been achieved based on a systematic literature search. Many studies show that the number of fatalities and the risk of severe or fatal injuries in rear impacts are low when compared to frontal and side impacts. A study showed that the odds of severe injury occurring in frontal impacts or side impacts are between 3 and 17 times higher than in rear impacts. However, risks of some types of injury may be relatively high after a rear impact, especially whiplash induced injuries. In severe rear-end impacts, It has been shown that the risk of a driver sustaining a whiplash induced injury is twice that of front seat passengers. In addition the risk of whiplash injuries for females is 3 times higher than the risk for males. Another problematic issue in rear impacts is the risk for rear seat occupants. Indeed, risk of severe injury to a rear occupant is two to four times higher than the risk for a front occupant. Some factors may worsen the situation for rear seat occupants such as the deformation of the front seat during the crash. For example, it has been shown that when front seat deformation occurs directly in front of a restrained child seated in an outboard rear row position, the odds of injury were 2.4 times higher; this indicates that some vehicle interior components may need to be given some more attention. This is borne out in a study that shows that when a driver contacts the armrest in a rear impact, they have a six fold increase in getting a severe chest injury than when no contact with the armrest happens. Other vehicle interior components have been reported as aggressive in a rear impact such as the door and the steering wheel.

4.4.5 Injury mechanism / Side impact: risk to be injured following nearside/farside impact

Colour Code: Red

The bibliographic review on side impacts suggests that this type of impact can be given the colour code **red** (risky). Although this type of impact does not account for the highest numbers of fatalities or severe injuries, it is by far the most risky for car occupants, especially in the case of near-side (struck side) impacts.

Abstract

Side impacts are impacts occurring to the side of a vehicle and generally defined by the principal direction of forces (PDOF) between 2, and 4, or 8 10 'o'clock or by the principal area of damage defined as the side of the vehicle. Many factors may influence the outcome of a side impact such like the position of the occupant in the vehicle (driver, front passenger, rear passenger), the impact location relative to the occupant position (near-side or far-side), the impact location on the vehicle side (front side, centre side, or side distributed), or the aggressiveness and protection capacity of different vehicle interior components.

A review on side impact risk factors has been conducted based on a systematic literature search. Results show that side impacts are more risky than frontal impacts and rear impacts. Most studies distinguish between two types of side impacts: near-side and far-side. In general, near-side impacts are associated with higher risks of severe or fatal injuries. The body regions that are more at risk were found to be the thorax, the lower extremities and the head. Impact location on the vehicle side has strong effect on the injury outcome of occupants. For example, in near-side impacts, vehicles with damage distributed along the side and vehicles with damage to the centre of the side are respectively 17 and 10 times more associated to driver severe chest injury than vehicles with side front damage. Some driver contact points inside the vehicle have been found to be more risky than others like the door, the armrest, and the driver's seat.

4.4.6 Injury mechanism / Risk to be injured in Rollover

Colour Code: Red

Risk of injury from a rollover accident is a red risk factor. Most of the studies agree on the fact that the risk of injury when involved in a rollover accident is greater than when not involved in such accident.

Abstract

The synopsis summarizes 9 articles. The aim of this synopsis is to summarize how the risk of injury for passenger car occupants involved in rollover crashes has been studied and what are the main results. Most papers analysed use North American databases. Rollover motor vehicle crashes account for a disproportionate number of serious injuries compared to crashes in planar modes. Several factors have been studied in order to better understand the injury mechanisms and to prioritize safety measures development.

The body type of the vehicle is one risk factor. Higher profile vehicles (SUVs, trucks, and vans) seem more protective during rollover than cars.

There is no difference found in the risk of death in a rollover between rear and front passengers. Nevertheless, the risk of death among rear-seated occupants was highest in rollovers than in frontal impacts.

Roof structure intrusion is a common factor that has an influence on the risk of injuries, especially for head, neck and spine body regions. In general, the higher the intrusion the higher the risk of serious injury.

Other passenger (age, BMI…) or accident (road condition, speed limit…) parameters have been taken into consideration in some articles (but not in most) and show consistent results.

4.4.7 Injury mechanism / Submarining & abdominal injury risk

Colour code: Red

Despite the abdomen not being the body region suffering the most injuries it remains one of the body regions most susceptible to severe injuries and complications because of the internal organs (such as liver or the spleen) which make up it. The progress made in passive safety during the last decades has advanced protection to some vital body regions (such as head, neck, thorax), however the abdomen did not receive such advantage with these improvements.

Abstract

The abdominal injuries are caused either by a direct contact with vehicle component (car door, steering wheel, armrest, console …) or by direct contact with passive safety components (seatbelt webbing, seatbelt anchor, airbags …) or inferred by a mechanism called submarining (sliding of the pelvis under the lap belt). Most of the epidemiological studies show that abdominal injuries are

mainly observed in frontal impacts. The progress made on vehicle structural performance and the development of better seatbelt systems and airbags allowed for a decrease in interior intrusion and direct contact with vehicle component (in frontal impact) but has increased the level of deceleration, possibly exacerbating the submarining mechanism. The abdominal injury risk varies over different seat locations. The more risky position are for the rear seats due to less optimized seat and belt geometry and less effective seatbelt systems (no pretensioner and few load limiter). Front passengers have a higher risk compared to the driver, essentially caused by a less optimised body position and a more distant dashboard/airbag.

4.4.8 Crash worthiness / Compatibility (self and partner protections) & age

Colour Code: Red

The bibliographic review on compatibility and vehicle age suggests that this type of impact can be given the colour code **red** (risky). Relevant studies showed that issues in vehicle compatibility may generate risks for car occupants. Compatibility issues between newer and older vehicles have been also outlined.

Abstract

Vehicle compatibility and vehicle age are two important factors when dealing with risks to passenger car occupants during a crash.

Compatibility refers to how well two vehicles match up in a two vehicle crash. Compatibility related risks are generated by a vehicle on its occupants and on the occupants of the impacted vehicle during a two vehicle crash. Two notions can be distinguished: "self-protection" or the vehicle's ability to reduce risks to its occupants and "partner protection" or the vehicle's ability to reduce risks to occupants of the impacted vehicle. Compatibility is an issue since passenger car designs are very varied and include cars of differing heights and mass. In addition, passenger cars crash into other types of vehicles, such as like light trucks, minivans, etc. which may not be optimised in terms of compatibility. Risks related to vehicle age can be studied from two complementary points of view: it can be seen as a difference in risks to occupants between older and newer vehicles or it could be viewed as a compatibility issue between older and newer vehicles.

A review on compatibility and vehicle age risk factors has been conducted based on a systematic literature search. Risk of injury in collisions between different car types (small saloons, luxury cars, sports cars, etc.) has been reviewed. Collisions between passenger cars and other types of vehicles (light trucks, minivans, etc.) have also been reviewed. Results show that heavier cars tend to be more risky for occupants of the opposing vehicle and more protective for their own occupants. For example, when a car impacts another car with a bigger mass ratio, the odds of severe or fatal injury for the driver in the lighter car is 28% higher than for the driver of the heavier car. Newer vehicles have the same effect on older vehicles occupants as the risk for drivers colliding against a newer car is higher than when colliding against an older car. For example, the mean risk of death for a car driver in collision with a car registered in 2004–2007 is about 23% greater than in collision with a car registered in 1988–1991. On the other hand, newer cars are associated with lower risk of injury than older cars in all other respects, namely protection of occupants in fatal and serious accidents. However, an elevated risk of death for rear row occupants, as compared with front row occupants, has been found in the newest model year vehicles. This provides evidence that rear seat safety is not keeping pace with advances in the front seat.

4.4.9 Crashworthiness / Low star rating (Euro NCAP)

Colour code: Yellow

The bibliographic review on Euro NCAP low star rating suggests that this topic can be given the colour code **yellow** (probably risky). Many studies showed that low star rated cars increase injury risks for occupants and pedestrians during an impact when compared to five star rated cars. On the other hand, low star rated car models represent a relatively low percentage of new cars sold in Europe.

Abstract

Euro NCAP's 5-star rating represents the gold standard of vehicle safety in Europe. The tests carried out by Euro NCAP are stricter than those required by regulation and have also become stricter over time. The rating has also evolved in order to become more representative of the whole safety environment of a car. Since 2009, cars have been tested in four different safety categories: adult occupant protection, child occupant protection, pedestrian protection, and safety assistance systems. In order to get 5 stars, a car should perform well in all four categories. If all these evolutions allow to improve the safety of occupants, they make difficult the comparisons in the time: for the same star rating the cars from a year to the other one are not comparable any more.

A systematic literature search and a bibliographic review have been achieved in order to highlight the particularity of low star rated cars in terms of risks that they represent to their occupants and to other road users like opponent car occupants, pedestrians, and cyclists. Most studies that we found were based on real-life accident data. Indeed, the performance of low star rated cars were observed in real-life accidents and compared to the performance of high star rated cars. Although the severities of different versions of Euro NCAP tests (depending on the year of the test) were not taken into account, results seem to be consistent and they all show significant safety differences between cars of low star categories when compared to cars of high star categories. In two car crashes, drivers of low rated cars are more at risk than drivers of cars with high Euro NCAP ratings. For example, if a crash happens between two cars of uneven Euro NCAP star ratings, the driver of the lower rated car has two times more chances of getting injured when compared to the driver of the higher rated car. No significant injury risk differences were seen for minor injury crashes but for fatal and serious injuries, 5-star cars presented 23% less risk when compared to 2-star rated cars and even 68% less risk of fatal injuries. With regards to cars with low ratings in the Euro NCAP pedestrian test, they were found more risky for pedestrians and cyclists especially when dealing with pedestrian head injury risk. For bicyclist injury, increased risks were only observed when comparing between medium (2 star) and high (3-4 star) performing cars.

4.4.10 Technical defects & Maintenance

Colour Code: Yellow

The colour code for technical defect risk is yellow. Indeed, it is not clear if the exposure to the risk factor increases the accident risk. But accident issues are very low in developing countries. Nevertheless, it is assumed that the rate of technical defects contributing to an accident is probably under-reported as a full (destructive) inspection is required in order to determine actual roadworthiness. And in most accident database, it is not the case.

Abstract

The synopsis stayed at the subtopic level (technical defect / maintenance) and not at a specific risk factor (Faulty headlights & taillights, Tire blow out, Faulty steering system and suspension, Faulty brakes, Airbag deployment at untimely moment…) because of the lack of available articles.

A roadworthy vehicle is one in which there exist no safety related defects at a particular time. Papers collected for this topic aim at identifying the prevalence of vehicles with roadworthiness defects in vehicle populations, the effect of vehicle defects on the incidence and severity of crashes and the effect of vehicle inspection on accident rates.

The number of vehicles (among the vehicle population) with a technical defect largely varies according to the paper: from 2% to almost 100%. Results are different according to the country (Russia, UK, Germany, South Africa, US…), the way the vehicle is inspected (full (destructive) inspection or not…), the organization in charge of the inspection (police services, vehicle experts…). In UK, approximately 40 % of vehicles in the UK failed their initial periodic technical inspection, although this varied depending on vehicle class, vehicle age and mileage at the time of the test. The rate of defects increases for older vehicle.

Vehicle defects are likely to be a contributory factor in 0.5% to 24% of accidents. Even if the interval is less large than the one for technical defects among vehicle population, it is still important (probably, for the same reasons as explained above).

The effect of vehicle defects on the prevalence of accidents is not clearly proven.

The effect of vehicle inspection on accident rates is different according to the papers. Two of them have not established a link between them whereas two others estimated to be improvements in injury crash involvement rates associated with an inspection and with the increase from annual to 6-monthly inspections.

4.5 RISK FACTORS RELATED TO LIGHT GOOD VEHICLE (LGV)

Light good vehicle or Light Commercial vehicle refers to a commercial carrier vehicle with a gross vehicle weight of not more than 3.5 tonnes. The fleet includes light commercial vehicles derived from passenger cars (Renault Kangoo, Mercedes Citan, Peugeot Partner, Citroën Nemo etc.), multipurpose vehicles (Ford Transit, Renault Trafic, Mercedes Viano etc.), or upper-medium size LGV (Renault Master, Fiat Ducato, VW Crafter etc.). These vehicles correspond to the type M1[11] and N1[12] of the European vehicle classification.

The commercial vehicle in use represented more than 329 million vehicles worldwide in 2014. In Europe this fleet counts about 38.448 million vehicles (137.043 in the US). This fleet is 6.5 times smaller than passenger cars(source ACEA).

[11] M1 : Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat, and having a maximum mass ("technically permissible maximum laden mass") not exceeding 3.5 tons

[12] N1 : Vehicles for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes

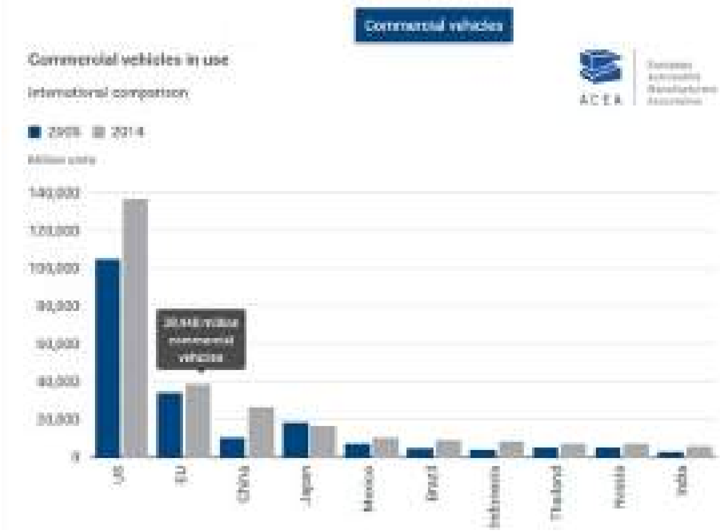


Figure 23 : Commercial vehicle in use in the world (source ACEA)

From the CARE database (year 2014) the proportion of LCV/LGV occupants represents approximatively 3% of the overall fatalities in EU (figure below).

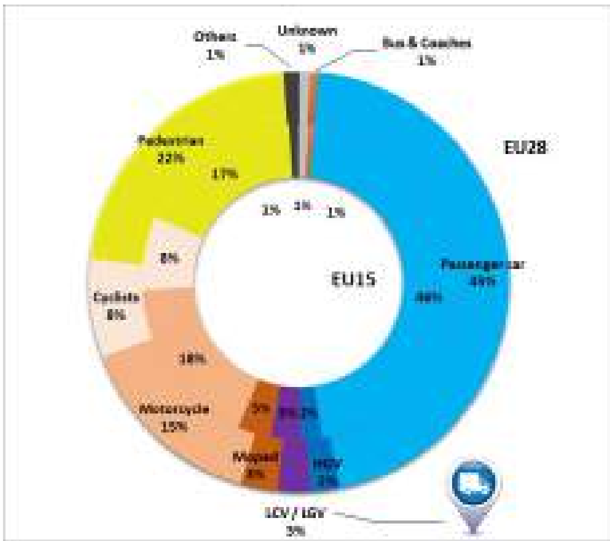


Figure 24 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

Compared to passenger cars or powered two wheelers (PTW), fatalities for the occupants of LCV/LGV is very low. However, the number of persons killed for LCV/LGV occupants is certainly higher due to the difficulty in the identification of these vehicle by the police, in particular those of the category N1, which are derived from passenger cars (Renault Kangoo, Peugeot partner, Citroen Berlingo etc.).

Among the European states, Portugal, Denmark and Cyprus have the highest rate of fatalities (respectively with 10%, 9% and 9% of the overall fatalities of the country).

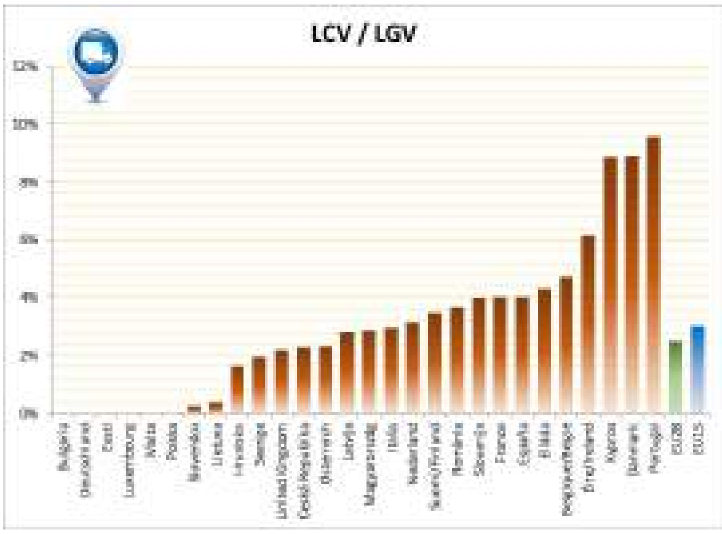


Figure 25 : Proportion of LCV/LGV occupant fatalities according to European countries (source CARE, year 2014)

If we look at severity according to the type of impact, we can see in France (2014) that frontal impact is the crash the most represented (66% of fatalities) following by the side impact (17%) and the rear impact (5%).

However, although frontal impact is the most frequent collision for LCV/LGV, we can see in the following table that rollover is the most severe impact (66 killed or severely injured occupants for 100 vehicle involved).

France 2014	No of vehicles	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 veh.)
Frontal impact	3345	95	609	741	704	21
Side Impact	631	25	84	119	109	17
Rear Impact	1072	7	55	264	62	6
Rollover or overturn	79	12	40	41	52	66
Others impact	195	4	16	33	20	10
Total	***5322***	***143***	***804***	***1198***	***947***	***18***

Table 17 : Distribution of the LCV/LGV occupants according to the severity and the type of impact (Source BAAC, France 2014)

4.5.1 SafetyCube scenarios dedicated to LCV/LGV

We consider here all injury accidents involving at least one LCV/LGV.

If we look at the distribution of the LGV occupant injuries according to the body region, AIS3+ injuries (in red) are more frequent for lower extremities (27%), the head (24%) and the abdomen (21%). For the AIS2+ injury level (in orange) the three most frequently injured body regions are the lower extremities (34%), the abdomen (17%) and the upper extremities (24%).

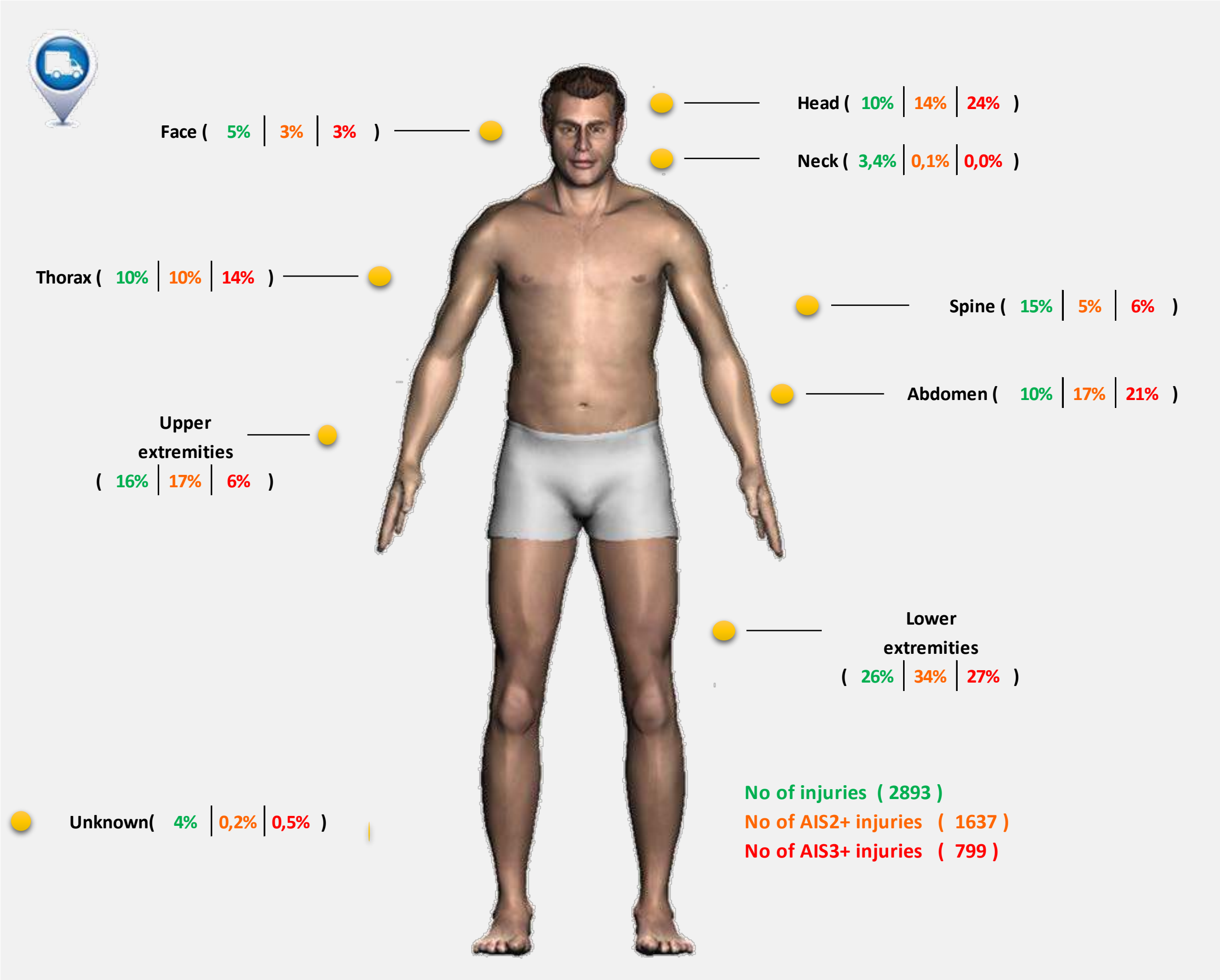


Figure 26 : LGV occupant: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

In France in 2011 (source VOIESUR), we count a total of 5,255 injury accidents involving 5,378 LCV/LGV.

For this category of vehicle, the most frequent scenarios are "Rear-end collision or same direction traffic" (25%), followed by "Head-On collision or on coming traffic" (14%) and accident "Out of junction" where the type of collision is unknown (13%).

The most deadly scenarios are "Head-on collisions or on coming traffic" (35%) followed by "pedestrian accidents" (15%) and "Single vehicle accident – run-off road" (12%).

The most severe accidents (number of KSI per 100 accidents) are "Head-on collisions or on coming traffic" (84 KSI) followed by "Single vehicle accident – run-off road" (71 KSI) and accidents with a pedestrian (33 KSI).

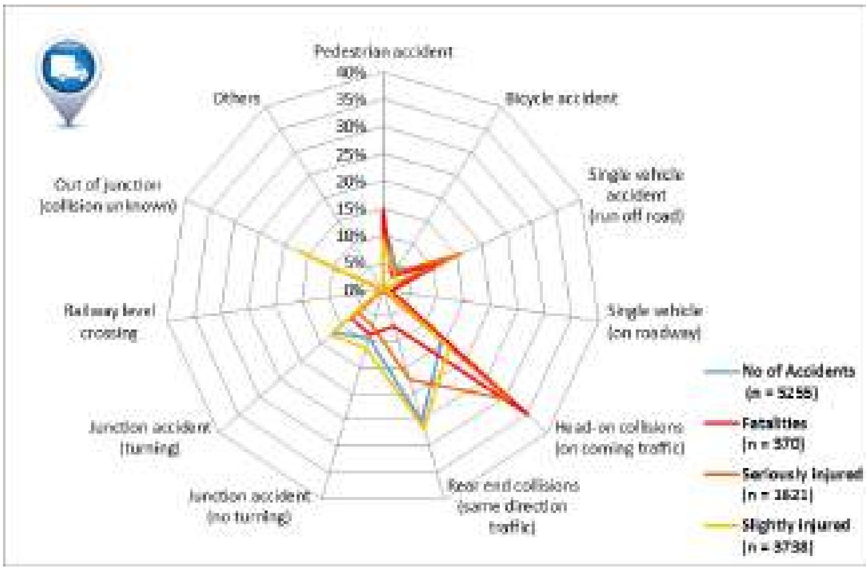


Figure 27 : Distribution of the LCV/LGV accidents scenarios according to the severity
(Source VOIESUR, France 2011)

France 2011	No of accidents	No of LCV	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)	KSI (for 100 veh.)
Pedestrian accident	656	656	54	160	328	214	33	33
Bicycle accident	248	248	11	63	132	74	30	30
Single vehicle accident - Run off road	424	424	46	253	111	299	71	71
Single vehicle - on roadway	50	50	6	0	23	6	12	12
Head-on collisions / on coming traffic	753	794	130	503	599	633	84	80
Rear end collisions / same direction traffic	1329	1347	26	276	989	302	23	22
Junction accident – no turning	481	499	32	113	417	145	30	29
Junction accident – turning	632	633	29	101	469	130	21	21
Railway level crossing	18	18	0	0	18	0	0	0
Out of junction - Collision unknown	664	708	36	152	653	188	28	27
Others	0	0	0	0	0	0	0	0
Total	***5255***	***5378***	***370***	***1621***	***3738***	***1991***	***38***	***37***

Table 18 : Accident characteristics according to the LCV/LGV scenarios
(Source VOIESUR, France 2011)

4.5.2 Prevalence of vehicle factors in crash data – Accident characteristics (driver, vehicle, infrastructure, impact, time of crash…)

Colour Code: Yellow

Accident characteristic is difficult to define as a risk factor, this synopsis rather describes LGV accident conditions. Most studies are descriptive analyses that focus on what, where, why, and when such accidents happened. Nevertheless, LGVs and LTVs are becoming more common, and could have a bad effect on road safety (more injury accidents). That is why the color code for this risk factor is yellow.

Abstract

The accident characteristics synopsis aims at describing which LGVs are involved in accidents, what the trip purpose was, who was involved, where inside the vehicle they were, how the accidents happened, and what are the crash conditions. Most of the studies inside the DSS are descriptive studies.

LGVs and especially LTVs are becoming increasingly more common. That means that the proportion of such vehicles in the vehicle fleet has been increasing for the last decade. This vehicle fleet change has an influence on road safety. Indeed, some studies assess that a 1% increase in light truck share would increase significantly the yearly number of road traffic fatalities. In Europe, LGVs are mainly goods cars (car derived vans) or a van (up to 12 m3 useful volume). They are mainly used on behalf of crafts businesses, companies and other trades persons.

Impact areas and age of killed road user inside LGV are similar to the figures found for passenger cars. The most frequent impact configuration is the frontal one and fatality rates increase as drivers' age increases. Nevertheless, LGVs are more often involved in intersection accidents. This synopsis includes several result such as: the consequence of a 1% LGV increase in the vehicle fleet, the body type description, the age and gender of LGV road users, the type of road on which the accidents happen and the kind of trip, and the accident and impact configurations. There is also a focus on emergency vehicles (ambulance, fire truck, police car etc.).

4.5.3 Prevalence of vehicle factors in crash data – Injury level

Colour Code: Grey

Injury level defines the risk of injury according to the body region and the vehicle type. The colour for this risk is grey as there are few studies and opposite effects found.

Abstract

The synopsis summarizes 5 articles. The aim of this synopsis is to have an overview of LGV-LTV injury risk according to the body region, the vehicle type and the impact location. Even if the risk of injury of light goods vehicle occupants is lower than those of passenger cars (even for occupant wearing a seat-belt); issues still remain. The articles estimate the risk of injury according to the body region and the vehicle type. Opposite results are presented in these articles. Bambach et al. (2013) found that the LTV occupant risk of sustaining serious thoracic injuries is 3.35 times more likely than car occupants. Desapriya et al. (2005) estimated that passenger car occupants have more risk to sustain a torso, head and neck injury that LTV occupants.

There is more risk to sustain lower limb injuries in a passenger car than in a LTV. And in far side impact, serious injuries to LTV occupants are almost uniformly distributed among head, chest, upper extremity, and lower extremity injuries. In passenger cars, with far side impact, chest and head injuries are the most frequent.

It is then difficult to conclude about injury level risk with only these results.

4.5.4 Crashworthiness / Self and partner protections

Colour Code: Red

Light Goods Vehicle (LGV) compatibility is significantly risky; indeed, mainly due to LGV dimension and weight, most papers conclude that there is a negative effect on road safety; especially for the opponent vehicle. In spite of the improvement done to improve protection and agressivity of LGVs, compatibility is still an issue. The color code is red.

Abstract

Vehicle compatibility is mainly defined and assessed according to the combination of its self-protective capacity and aggressivity when involved in collisions with another vehicles. Self-protection centres on a vehicle’s ability toshield its occupants in a collision, whereas aggressivity is measured by the casualty outcomes on occupants of the other vehicles in the collision. As the relative composition of the fleet of vehicles is altered (the number of LGV/LTV is growing in North America and Europe), negative effects on road safety might appear (Fredette et al., 2008). Most studies focus on the compatibility between LGV and passenger cars, as it is the most common accident configuration. The overall conclusion is that the risk of injury at all levels of severity is greater in cars than in LGVs.

4.5.5 Visibility and conspicuity / Visibility limitation due to the design

Colour Code: Red

Visibility limitation due to design is a red risk factor for LGVs. Indeed, even if there are few articles in the DSS, all the conclusions are the same. LGVs are mainly higher and larger than passenger cars, and these size differences have an influence in rear-end collisions; especially when a car driver is following an LGV.

Abstract

The synopsis summarizes 4 articles and deals with the risk of having an accident according to the visibility limitation of LGVs (because of its design). All the papers analysed focus on the risk of being involved in a rear-end collision involving a passenger car and a LGV. The LGV is the followed vehicle. Methodologies differ according to the article: accident data analysis and modelling, driving simulator experiment or FOT (Field Operational test) analysis. Conclusions are the same. There is a higher chance of rear-end crashes when a regular passenger car follows an LTV than when it follows another passenger car. Gap distances for following LTVs are significantly smaller than those for following a passenger car

4.6 RISK FACTORS RELATED TO TRUCK (HGV) AND BUSES

Heavy Goods Vehicles (HGV) and Buses are commercial vehicles designed for specific goods or personal transport. This category includes commercial vehicles with a gross vehicle weight over 3.5 tonnes.

The literature was reviewed using the SafetyCube guidelines and 37 journal or conference articles were found to fit the criteria. These articles were used to identify the significance of the following risk factors. Due to a shortage of papers that could well describe each risk factor, definitive colour coding was not always possible.

Unless mentioned otherwise, the risk of injuries or crash involvement in this section are taken for the occupants of the HGV or Bus as other road users are discussed in the other sections.

From the CARE database (year 2014) the proportion of HGV occupants (respectively Bus & coaches) represents approximatively 2% (resp. 1%) of the overall fatalities in the EU28 (figure below).

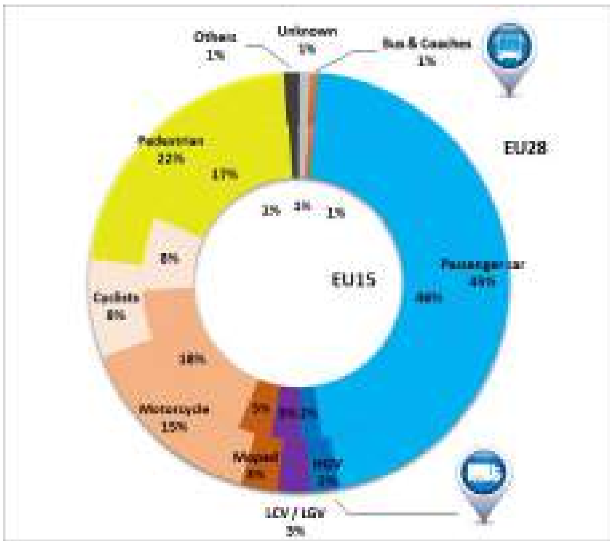


Figure 28 : Proportion fatalities according to road user type in Europe (source CARE, year 2014)

Compared to the other type or road users the fatalities for the occupants of HGV and Bus are very low.

Regarding HGVs, among the European states, Estonia, Slovenia and Germany have the highest rate of fatalities (respectively with 6%, 5% and 4% of the overall fatalities of the country).

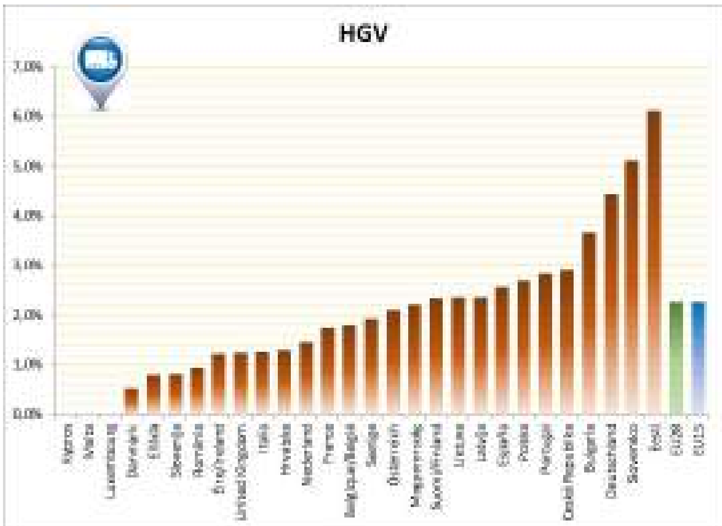


Figure 29 : Proportion of HGV occupant fatalities according to European countries (source CARE, year 2014)

Regarding Bus & coaches, among the European states, Estonia, Portugal and Italy have the highest rate of fatalities (respectively with 2%, 1.7% and 1.4% of the overall fatalities of the country), although these rates are still very low.

Figure 30 : Proportion of Bus & Coaches occupant fatalities according to European countries (source CARE, year 2014)

If we look at severity according to the type of impact, we can see in France that most frequent crash type for HGVs is "frontal impact" (79% of fatalities) followed by the side impact (13%) and the rear impact (7%).

However, although frontal impact is the most frequent collision for HGVs, we can see in the following table that rollover is the most severe impact (68 killed or severely injured occupants for 100 vehicles involved).

France 2014	No of vehicles	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 veh.)
Frontal impact	1667	44	189	224	233	14
Side Impact	381	7	49	48	56	15
Rear Impact	618	4	15	43	19	3
Rollover or overturn	31	1	20	11	21	68
Others impact	220	0	22	24	22	10
Total	***2917***	***56***	***295***	***350***	***351***	***12***

Table 19 : Distribution of the HGV occupants according to the severity and the type of impact (Source BAAC, France 2014)

For the Bus & coaches category, occupants were only killed in frontal impact in France in 2014, although the total number of fatalities is low so this may not be fully representative of all years. This type of impact is also the most severe (13 killed or severely injured occupants for 100 vehicles involved).

France 2014	No of vehicles	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 veh.)
Frontal impact	626	9	75	321	84	13
Side Impact	113	0	6	24	6	5
Rear Impact	116	0	4	25	4	3
Rollover or overturn						
Others impact	67	0	3	47	3	4
Total	***922***	***9***	***88***	***417***	***97***	***11***

Table 20 : Distribution of the Bus & Coaches occupants according to the severity and the type of impact (Source BAAC, France 2014)

4.6.1 SafetyCube scenarios dedicated to Trucks (HGV)

We consider here all injury accidents involving at least one Truck.

If we look at the distribution of the HGV occupant injuries according to the body region, AIS3+ injuries (in red) are more frequent for the upper extremities (27%), the thorax (23%) and lower extremities (23%). For the AIS2+ injury level (in orange) the three most frequently injured body regions are the thorax (25%), the lower extremities (25%), and the upper extremities (24%).

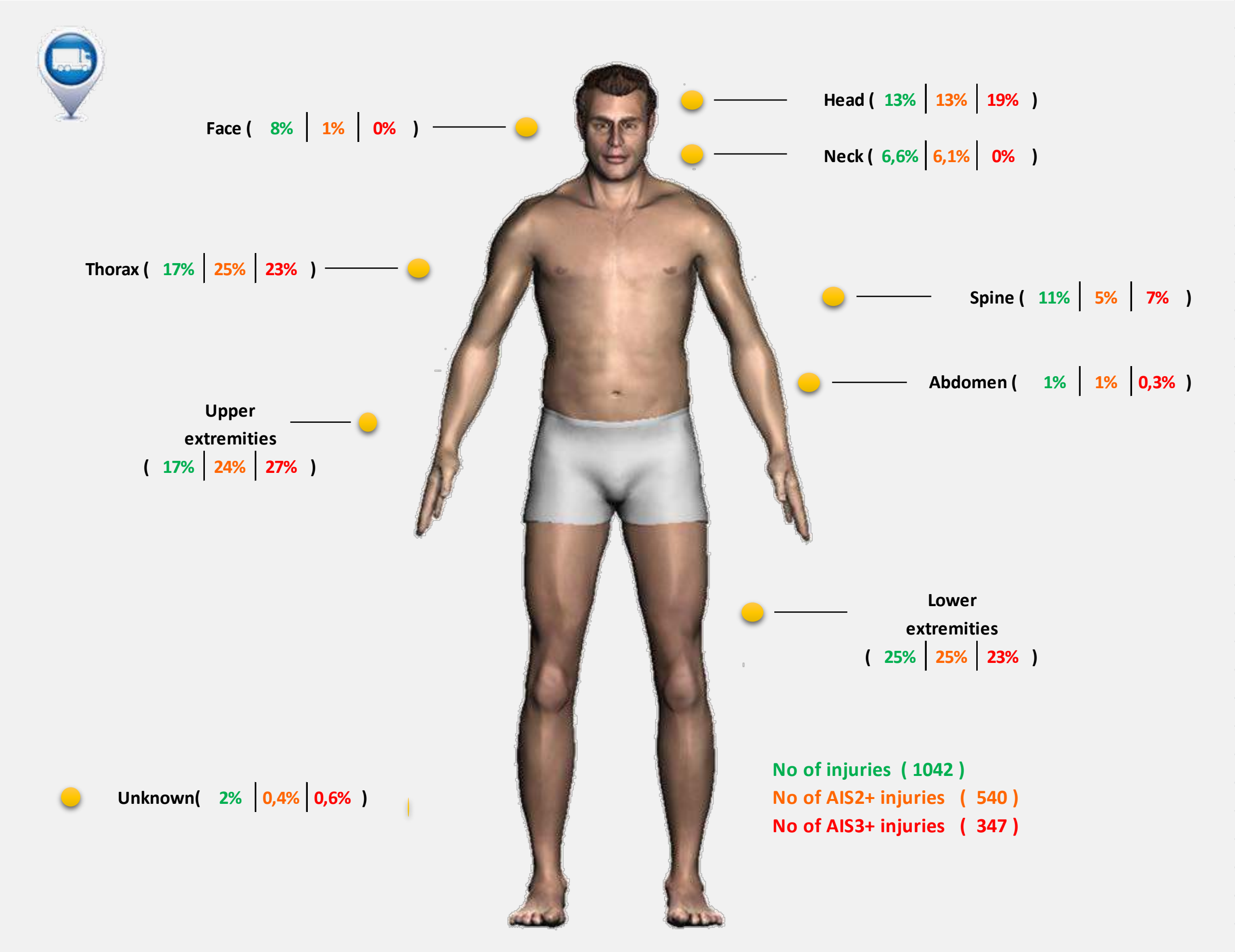


Figure 31 : HGV occupant: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

In France in 2011 (source VOIESUR), we count a total of 3,554 injury accidents involving 3,750 HGV. For this category of vehicle, the most frequent scenarios are "Rear-end collision or same direction traffic" (39%), followed by "Head-On collision or on coming traffic" (14%) and accident "Out of junction" where the type of collision is unknown (11%).

The most deadly scenarios are "Head-on collisions or on coming traffic" (37%) followed by "Rear-end collision or same direction traffic" (17%) and pedestrian accidents (13%).

The most severe accidents (KSI for 100 injury accidents involving a HGV) are "Railway level crossing" (196 KSI) followed by "Bicycle accidents" (109 KSI) and "Head-on collisions or on coming traffic" (101 KSI).

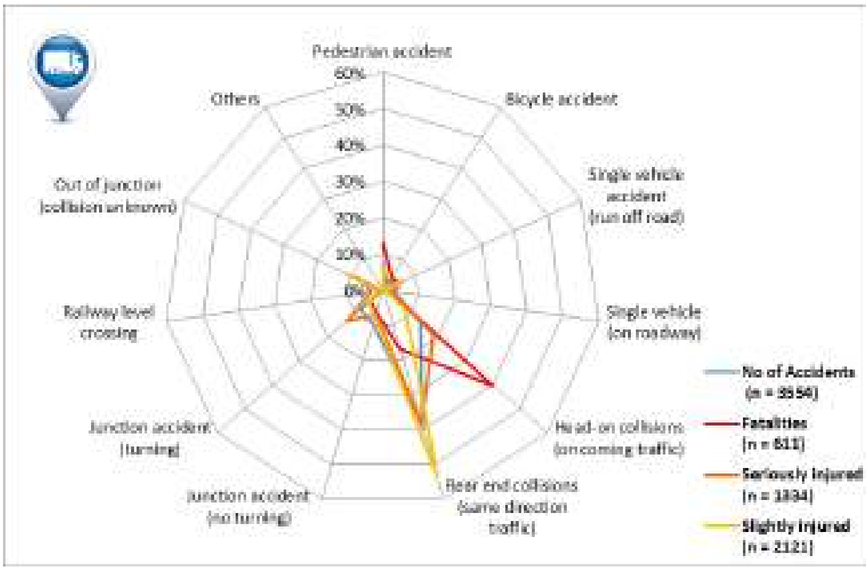


Figure 32 : Distribution of the HGV accidents scenarios according to the severity (Source VOIESUR, France 2011)

France 2011	No of Accidents	No of HGV	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)	KSI (for 100 HGV.)
Pedestrian accident	258	260	78	46	137	124	48	48
Bicycle accident	65	65	26	45	0	71	109	109
Single vehicle accident - Run off road	204	204	30	57	135	87	43	43
Single vehicle - on roadway	114	114	9	33	22	42	37	37
Head-on collisions / on coming traffic	486	547	245	246	172	491	101	90
Rear end collisions / same direction traffic	1401	1472	104	514	1140	618	44	42
Junction accident – no turning	335	337	38	95	155	133	40	39
Junction accident – turning	285	285	27	175	112	202	71	71
Railway level crossing	23	23	1	45	1	46	196	196
Out of junction - Collision unknown	383	442	52	77	244	129	34	29
Others	0	0	1	2	3	0	0	0
Total	***3554***	***3750***	***611***	***1334***	***2121***	***1942***	***55***	***52***

Table 21 : Accident characteristics according to the HGV scenarios (Source VOIESUR, France 2011)

4.6.2 Safetycube scenarios dedicated to Bus & Coaches

We consider here all injury accidents involving at least one Bus or coach.

If we look at the distribution of the Bus occupant injuries according to the body region, all AIS3+ injuries (in red) are located in the upper extremities.

This result has to be used carefully firstly because the number of injury accidents involving a Bus in 2011 is very low. Secondly, taking into account the high number of carried occupants compared to other categories of vehicle, the figure can be totally different from year to another.

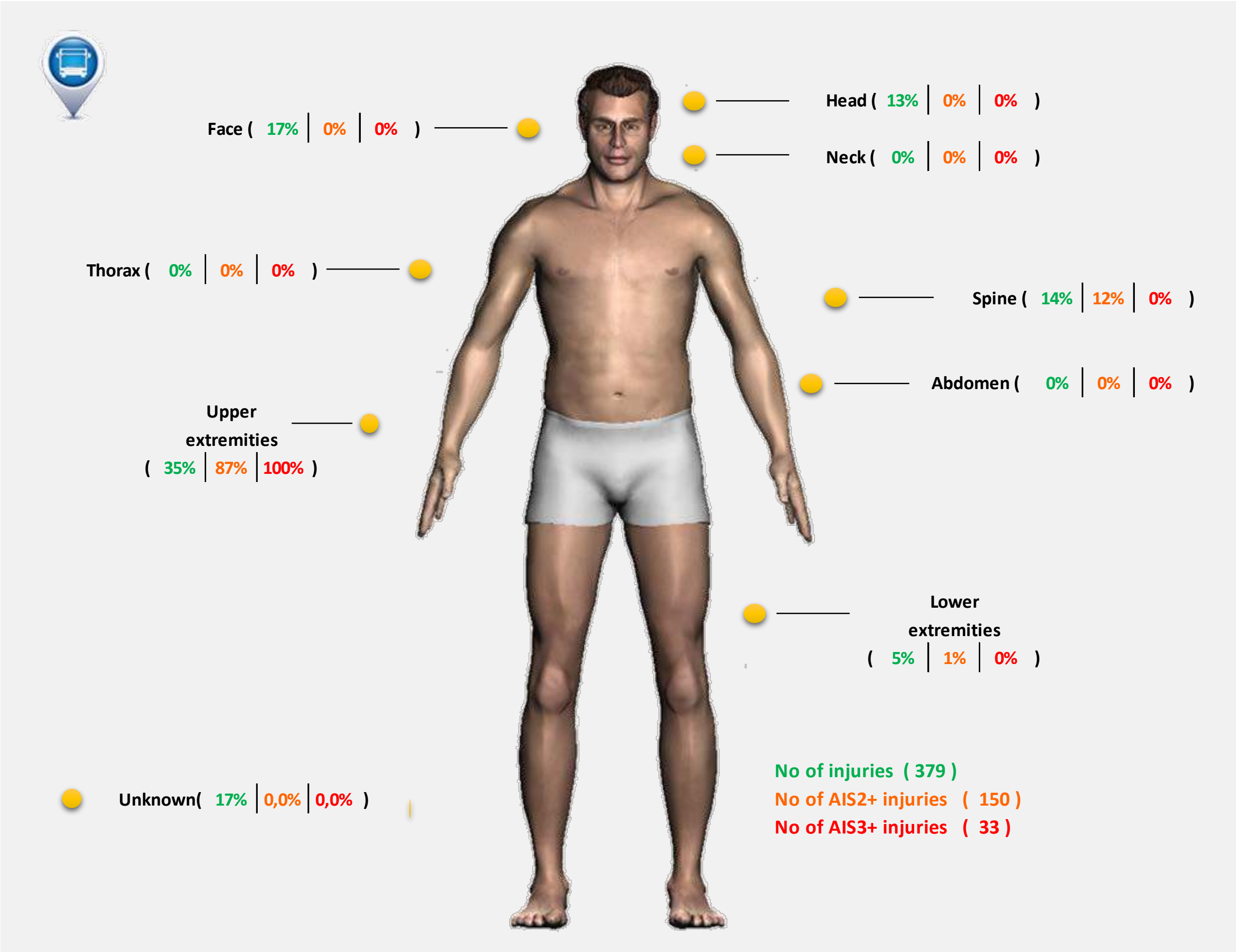


Figure 33 : Bus occupant: Distribution of injuries frequency according to the body region and the severity all injuries (green), AIS2+ (orange) and AIS3+ (red) (source VOIESUR, 2011)

In France in 2011 (source VOIESUR), we count a total of 957 injury accidents involving 957 vehicles. For this category of vehicle, the most frequent scenarios are "Pedestrian accident" (32%), followed by "Rear-end collision or same direction traffic" (14%) and accident "Junction accident with no turning" (11%).

The most deadly scenarios are Pedestrian accidents (33%) followed by "Railway level crossing" (21%) and "Head-on collisions or on coming traffic" (18%).

The most severe accidents (KSI for 100 injury accidents) are "Single vehicle – on roadway" (200 KSI) followed by "Head-on collisions or on coming traffic" (70 KSI) and "Bicycle accident" (38 KSI).

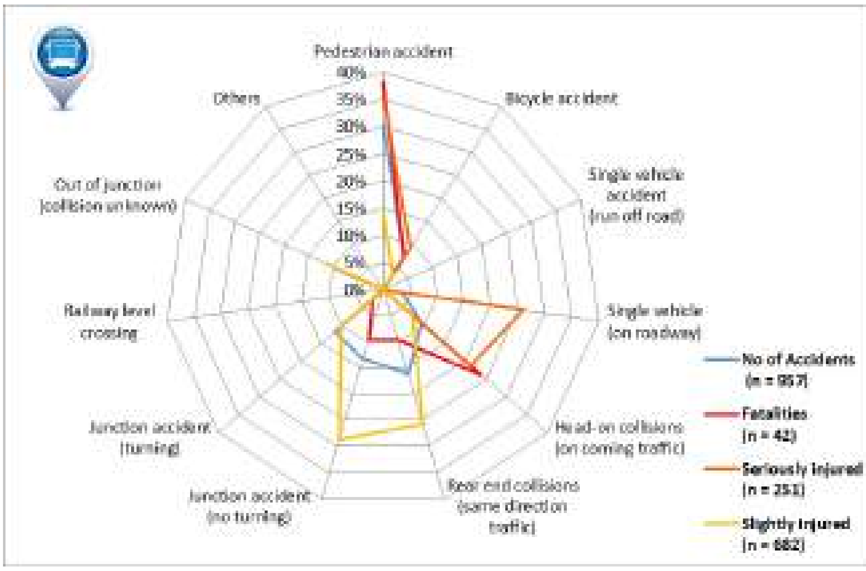


Figure 34 : Distribution of the Bus & Coaches accidents scenarios according to the severity (Source VOIESUR, France 2011)

France 2011	No of Accidents	No of Bus & Coaches	Fatalities	Seriously injured	Slightly injured	KSI	KSI (for 100 acc.)	KSI (for 100 veh.)
Pedestrian accident	292	292	16	89	95	105	36	36
Bicycle accident	69	69	3	23	22	26	38	38
Single vehicle accident - Run off road	0	0	0	0	0	0	0	0
Single vehicle - on roadway	33	33	0	66	0	66	200	200
Head-on collisions / on coming traffic	90	90	10	54	49	64	70	70
Rear end collisions / same direction traffic	155	155	4	0	175	4	3	3
Junction accident – no turning	126	126	4	1	195	5	4	4
Junction accident – turning	111	111	1	18	68	19	17	17
Railway level crossing	0	0	0	0	0	0	0	0
Out of junction - Collision unknown	81	81	4	0	78	4	5	5
Others								0
Total	***957***	***957***	***42***	***251***	***682***	***293***	***31***	***31***

Table 22 : Accident characteristics according to the Bus & Coaches scenarios (Source BAAC, France 2014)

4.6.3 Prevalence factors in crash data / Driver characteristics

Driver gender could be a risk factor for heavy vehicles if the vehicle interior and restraint system are not designed with female statures or biomechanics in mind. Driver states (fatigue, drug or alcohol use, etc.) are also a risk for these heavy vehicles and are covered more extensively in WP4.

Colour Code: Grey

Abstract

Heavy truck and bus drivers are predominantly male and have additional training due to the requirement of a more demanding driver's license. The data indicated the bias to male drivers involved in crashes, however there are not enough female drivers in the population to control for gender effects. Fatigue may be more prevalent in HGV and Bus crashes as professional drivers are driving for longer periods than commuters or recreational drivers.

Fatigue and drug use is associated with many truck and bus crashes, however these studies address only the population of commercial drivers and do not relflect the entire driving population. Male drivers are more common and gender effects on crash and injury risk for the occupants cannot be controlled for gender.

4.6.4 Prevalence factors in crash data / Vehicle characteristics

The type and size of trucks may play a role in the risk of a crash. Main design features of interest are the length, total mass, and the number of articulations. Buses may be articulated to allow longer vehicles to operate in city environments. HGVs can consist of one or more trailers.

Colour Code: Grey

Abstract

There are conflicting reports on the role of the vehicle design on crash or injury risk. While one reference indicated a higher crash risk for trucks with more than one trailer, another study found the opposite. There tends to be more crash risks for single unit (as opposed to articulated) trucks. Buses with large side areas are reported in crashes with high side winds but no definitive risk data is available. The number of articulations seems to increase the risk for crashes when road and weather conditions are poor.

It is not clear if the design (size, mass, articulations) is a risk factor for crashes and injuries. Conflicting results were found. More complex (articulated) trucks may be more susceptible to crashes in slippery/poor road conditions.

4.6.5 Prevalence factors in crash data / Impact characteristics

Colour Code: Yellow

Crashes of HGVs or buses are described in crash databases with different information levels. The high mass and large size of these vehicle result in more severe (high energy) crashes than other vehicles. Thus the consequences of the crashes tend to be higher, particularly for smaller vehicles involved in a crash with this vehicle type. The vehicle properties can make the vehicle more prone to certain crashes.

Abstract

Studies of heavy vehicle crashes tend to focus on specific crash types so there is a bias in the data presented. Rear-end and roll-over crashes are often studied separately as specific, high frequency crash types. The higher centre of gravity makes the larger vehicles more prone to rollover than other vehicle types. Rollovers can occur in both single and multi-vehicle crashes. The most relevant study addressing crash types and consequences (Islam, 2014) shows rollover as an issue for single and multiple vehicle crashes for both urban and rural settings.

HGV and buses have a higher risk for rollover than other vehicle types. The papers covering this crash type are often biased to analysing datasets focusing on single vehicle crashes, giving a skewed analysis. There is a higher risk of rollover for heavy trucks and buses.

4.6.6 Prevalence factors in crash data / Injury level

Occupants of trucks and buses have different environments than passenger cars. Except for single vehicle crashes, these occupants are generally not exposed to as high crash conditions as occupants for smaller vehicles.

Colour Code: Grey

Abstract

Most crash databases highlight a lower incidence of injuries for HGV and bus occupants. The majority of safety literature addresses safety for the passenger car occupants which are more numerous and more severe. Injury risk and severity is influenced by crash type so there is no single way to describe a general injury risk. In vehicle-vehicle crashes, the occupants of the larger vehicle are less at risk (relative to the smaller vehicle), while there is a slightly higher injury risk of injury in the bus and HGV in a rollover situation.

Heavy trucks and buses provide different protection levels to their occupants depending on the crash type, and except for HGV-HGV and Bus-Bus crashes, there are lower risks for the HGV and bus occupants. The opposite is true for single vehicle crashes although the increased safety is not noticeably higher.

4.6.7 Visibility / Conspicuity / Blind Spot issue by right turning trucks

Colour Code: Red

The review on accidents involving right turning trucks and VRUs suggests that this type of accident can be given the colour code **red** (risky). This choice comes from the fact that most of these accidents result in a severe or fatal injury for the involved VRU. This is based on the big mass difference of the accident opponents and the high risk for the vehicle to run over the VRU.

Abstract

Accidents with right turning trucks mostly happen with pedestrians or cyclists. Due to the big mass difference and high risk for overrun, a large proportion of these accidents end in severe or fatal injury of the VRU. The main reason for this type of accident is the blind spot of the HGV.

This document is a review of the risks for VRU by the blind spot of a HGV. A systematic literature search has been achieved and relevant studies have been analysed. These studies were very homogeneous in their nature. Results show that most accidents with right turning trucks and VRUs happen between 6 a.m. and 6 p.m. and during the working days. Cyclists older than 65 years are at a higher risk to get fatally injured during an accident with a right turning truck. Most impacts are on the right sight of the driver's cabin.

5 Conclusion

For each specific risk factor of the vehicle taxonomy, a systematic search of the literature was undertaken. The identified relevant studies were coded using a uniformed 'coding template'. This captured quantifiable objective findings about crash risk, frequency and severity influenced by the risk factor. Where sufficient studies could be identified, a synopsis was written summarising the impact of the risk factor on road safety. Each synopsis has a common format which starts with a colour code indicating the level of evidence available as to the risk imposed. This is followed by an abstract providing a summary of the findings for this risk factor.

The following table presents the risk factors separated by colour code.

Table 23: vehicle related risk factor synopses by colour code

Red (Risky)	Yellow (Probably risky)	Grey (Unclear)
! Pedestrian characteristics	! Ped. / Vehicle design	? Pedestrian / Time of crash
! Pedestrian / Type of vehicle striking	! Ped. / Low NCAP rating	? Pedestrian / Impact characteristics
! Bicycle / Accident characteristics	! Bicycle / Visibility - Conspicuity	? Pedestrian / Visibility / Conspicuity
! Bicycle / Injury severity in accidents	! PTW / Poor helmet performance	? PTW / Crash characteristics
! Pedestrian / injury level	! PC / Prevalence of vehicle factors in crash data	? PTW / Vehicle characteristics
! PTW / impact characteristics	! PC / injury mechanism / Rear impact	? PTW / Other protective equipment
! PTW / injury level	! PC / Low star rating	? PTW / Faulty headlight or taillight
! PC / Injury mechanism / frontal impact	! PC / Technical defects / Maintenance	? PTW / Faulty steering and suspension LGV / Crash data
! PC / injury mechanism / Side impact	! LGV / Accident characteristics	? HGV / Crash data
! PC / injury mechanism / Rollover	! LGV / Impact characteristics	? HGV / Vehicle data
! PC / Abdominal injuries & submarining	! HGV / Impact characteristics	? HGV / Injury level
! LGV / self & partner protection		
! LGV / Visibility		
! HGV / Blind spot issue		

Unfortunately it was not possible to produce a synopsis for all specific risk factors listed in the taxonomy.

The limitations of this work should be noted. The process of allocating colour codes was related to both the magnitude of risk observed, the level of evidence for this, and on expertise when not enough evidence was found.

Findings are limited by the implemented literature search strategy, the quality of studies, and sometimes by the number of studies identified.

Due to resource constraints, prioritising of study coding was necessary for risk factors with many identified studies. The criteria for prioritising within each synopsis is detailed in the supporting document. This approach focused on studies with the highest methodological quality, however it is possible that some detail of level of risk may have been missed by failure to consider a broad range of methodological approaches. Finally, within the considered literature, crash risk and crash frequency are much more commonly studied than crash severity. For some risk factors this makes it difficult (or impossible) to consider the implications for injury causation.

5.1 NEXT STEPS

The coded studies and synopses for the vehicle risk factors will be accessible to the users of the DSS. The colour code for each specific risk factor will be clearly presented within the DSS itself. Users will have the option to undertake a search of the DSS in several ways, and regardless of the type of search (entry point from which a user enters the DSS) results will always be presented in a consistent manner. For details on the way the results in the present report will be integrated / presented in the DSS, please see Deliverable 8.1 of SafetyCube.

The next task of SafetyCube is to begin identifying measures that will counter the identified risk factors (in this case those that relate to the vehicle). Most of the safety systems (on the market or in development) are not directly connected to risk factors but rather on accident configuration. For example, the ESC was developed to avoid the loss of control of the vehicle, not to prevent the associated causes such as inattention or drowsiness. This is the case for a large panel of safety systems which tend to correct the consequences rather than fight against the initial cause.

For this next step, methodological guidance has been provided as part of Deliverable 3.3 (Martensen et al., 2017). This notes that not all risk factors are equally mitigated by implementation of road safety measures. Furthermore, it is vital that the appropriate measure is applied to the appropriate risk factor.

The next step in Task 6.2 will be to identify the vehicle countermeasures that can counter the risks identified in the current document, summarise their safety effects in a similar way that the risks were summarised, and subsequently evaluate their cost-benefit and cost-effectiveness within Task 6.3.

References

[1] Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale 1990 revision-Update 98 Des Plains, IL 60018. USA: Association for the Advancement of Automotive Medicine.

[2] E. Amoros, A. Lardy, J.L. Martin, Rapport VOIESUR – *Méthodologie redressement et extrapolation*, Livrable L3, V2, January 2015

[3] R. Fricheteau, V. Phan, Rapport VOIESUR – *Livre de codage des variables générales*, V8, July 2014

[4] R. Fricheteau, V. Phan, Rapport VOIESUR- *Livre de codage des variables expertes*, V9, October 2014

[5] ONISR, Description des bases de données annuelles des accidents corporels de la circulation routière Années de 2005 à 2015, september 2016

[6] Martensen, H. et al. (2017). Methodological framework for the evaluation of road safety measures. Deliverable Number 3.3 of the H2020 project SafetyCube.

[7] Naing, C., Bayer, S., Van Elslande, P., Fouquet, K. (2007). Which Factors and Situations for Human Functional Failures? Developing Grids for Accident Causation Analysis. Deliverable of the EU FP6 project TRACE.

[8] DaCoTa. (2012a). Roads, Deliverable 4.8q of the EC FP7 project DaCoTA.

[9] Wallén Warner, H., Ljung Aust, M., Sandin, J., Johansson, E., Björklund, G. (2008). Manual for DREAM 3.0, Driving Reliability and Error Analysis Method. Deliverable D5.6 of the EU FP6 project SafetyNet.

Appendix - Synopses

This appendix includes all the vehicle synopses that are available as of October 2016. These will be available through the DSS when it is launched in 2017. The synopses are intended to be periodically updated to reflect new research or in some cases to expand their scope. Future updates or additions to the synopses will be available on the project website (http://www.safetycube-project.eu/) and the DSS.

Pedestrian - Vehicle shape

1 Summary

Reed S., Loughborough University, September 2016

1.1 COLOUR CODE: YELLOW

International literature indicates that differences in vehicle shape, particularly when considering taller or more aggressive vehicle such as light vans and sports utility vehicles (SUVs) leads to more severe pedestrian injuries and a higher risk of fatality.

1.2 KEYWORDS

Pedestrians, vehicle shape, light trucks, passenger vehicles, SUVs

1.3 ABSTRACT

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the shape of the vehicle. It has been estimated that the effect of being hit by a more 'aggressive' vehicle relates to a 3 fold increase in fatality risk, in other words being hit by a light truck/pickup can result in a significantly higher fatality risk than being hit by a standard passenger car. In addition, although to a lesser degree than fatalities, there is evidence of increased injury risk for light trucks, motorcycles and SUV vehicle shapes. Most research has been conducted in the USA where the vehicle fleet features proportionally more 'aggressive' vehicles however fleet changes in the EU make the result recently more relevant.

1.4 BACKGROUND

What is vehicle shape?

Vehicle shape in this context relates to the overall 'silhouette' of a vehicle, that is to say ignoring the 'micro' elements of the design, for example details such as bonnet curvature, head light material or bumper absorption measures and instead looking purely at the overall or 'macro' shape of the vehicle. Commonly shape in this context is classed in a number of broad groups such as light trucks (pickups and panel vans) and SUVs (passenger vehicles with raised suspensions in the mould of an off road vehicle). Results reported are normally with reference to passenger vehicles as these have either required pedestrian protection testing or already present a less aggressive impact for a pedestrian. Figure 1 below shows a basic schematic of vehicle shape silhouettes.

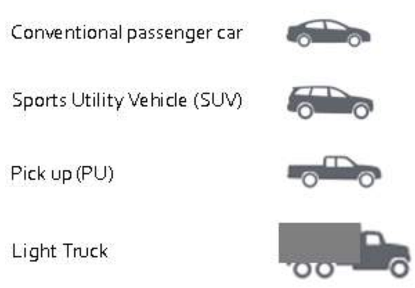


Figure 1: Vehicle shape silhouettes

How does vehicle shape effect road safety?
Vehicle shape effects road safety as it can present different levels of protection to a pedestrian (or other vulnerable road user) in the event of a collision. A more aggressive vehicle shape, for example a vehicle with a higher, more rigid and blunter front end will provide comparatively less protection to a pedestrian compared to a lower, softer and smoother front of another vehicle.

Which safety outcomes are affected by vehicle shape?
In the international literature, the effect of vehicle shape on road safety has been measured mainly on one basic outcome, namely injury outcome. This can be in terms of fatalities or other injury outcomes.

How is the effect of vehicle shape studied?
International literature shows that the effect of vehicle shape on injury outcomes is usually examined by analysis of real world collision data. Injury severity results are generally provided as an Odds Ratio (OR) or Relative Risk (RR) through simple associations. The studies identified all used data from the USA with certain selections made on road type to control for vehicle speeds and grouping of some vehicle classifications to improve statistical power.

1.5 OVERVIEW RESULTS

Most studies indicate that pedestrians hit by Sports Utility Vehicles (SUV's) and Pick-ups (light trucks) were more likely to have more severe injuries and more likely to die especially at low impact speeds (≤30 kph). In general it appears that a collision between a pedestrian and a more aggressive vehicle shape, for example a light truck or a sport utility vehicle, will result in an increased risk of more serious or fatal injuries than could be expected with a collision with a conventional passenger car.

1.6 NOTES ON ANALYSIS METHODS

In general, the coded studies are of sufficient quality and are methodologically sound being as they are based on the long established analysis of real world collision data. In keeping with the data source all studies use relatively large sample sizes for investigation. There can be data quality issues especially when considering such large data sets, however all studies appear to apply sound selection methodologies to the data sets with respect to road types, road speed limits etc.

With vehicle manufacturers constructing a range of different models with comparable body shapes, for example SUV body shapes in compact, mid-sized and large size classes it was necessary for some studies to apply some selection to the classification of vehicles shapes. In some cases it was necessary for vehicles to be merged into groups of vehicle shapes, for example the light truck category may in one case include small vans and pick ups or in some cases small vans, pickups *and* SUVs. The study specific selection has been used to best represent the overall vehicle shape and does not preclude the comparison of vehicle shape to conventional passenger cars.

Overall, the topic has been well studied. Research was mostly carried out in the United States where the proportion of pick up and SUV style vehicles is higher in the general vehicle fleet. Although other countries may not have the concentration of these vehicle types at present the population will likely increase in the future as vehicle manufacturers attempt to meet public demand, this should have the effect of making the result presented here more transferable to European member states.

2 Scientific Overview

2.1 LITERATURE REVIEW

Overall vehicle shape can be considered a major factor in the level of passive safety afforded to vulnerable road users in the road network, for example the level of protection provided by a large and heavy vehicle such as a heavy truck or bus could be considered less than that provided by a conventional passenger vehicle. These differences can be evident throughout the vehicle fleet with vehicles of the same class i.e. one model of passenger car Vs another model of passenger car providing different levels of protection to vulnerable road users.

Only relatively recently has pedestrian protection become a major pillar in the decision making for private buyers of vehicles with the introduction of pedestrian testing into NCAP protocols. This does not extend to all vehicle types such as commercial or public service vehicles which do not have to fulfil such detailed pedestrian protection testing/legislation.

From the studies identified in the international literature it appears that vehicle shape has an overall significant negative impact on pedestrian injuries and fatalities, that is to say that pedestrians hit by Sports Utility Vehicles (SUV's) and Pick-ups (light trucks) were more likely to have more severe injuries and more likely to die than in collisions with conventional passenger vehicles. All studies analysed show similar results particularly with reference to the more aggressive vehicle shapes.

Henary et al (2003) showed that compared to passenger cars, pedestrians hit by LTVs were more likely to sustain higher injury severities and more likely to die. This was especially clear at low impact speeds (≤ 30 km/h) and less so at higher impact speeds (> 30km/h) where the overall effect of vehicle shape is gradually eliminated by the increased impact force irrespective of vehicle shape.

Roudsari et al (2004) adds to the work conducted by Henary et al and suggests that the pedestrian injuries and fatalities by vehicle shape are influenced, at least in part, by the front end design of the vehicle. In general they conclude that vehicle type strongly influences risk of severe injury and death to pedestrian. Results from the study showed that adults struck by light trucks (LTVs) had a higher risk of moderate injury than those struck by either passenger vehicles or vans. As injury severity increased to include severe injuries results showed that pedestrians struck by LTVs were 2.1 times more at risk of severe injuries than other vehicle types.

In terms of pedestrian mortality, which was a major outcome variable in the study, the risk of death for LTVs was 3.4 times higher than for other vehicle types however the data did not show any considerable difference in risk of death between van collisions and conventional passenger vehicle collisions suggesting that vans perform comparably to the safer vehicle shapes.

Reflecting the results of Roudsari, Ballesteros et al (2002) found a similar pattern between pedestrian mortality and the type of the vehicle involved in the crash. Results indicate that Pedestrians hit by a conventional automobile died in 12.6% of the crash cases examined whereas this figure was 24.1% and 17.8% for the two most aggressive vehicle shapes of SUV and LTV respectively. Results for vans were not statistically significant but do indicate a similar result to those reported by Roudsari et al with a 13.7% risk of mortality.

Considering non-fatal collisions results show that being hit by an SUV or LTV resulted in an overall higher pedestrian ISS score. Although the relationship between vehicle type and pedestrian ISS was not statistically significant, results indicate that those pedestrians struck by an SUV, LTV or van had higher ISS scores compared to those struck by a conventional vehicles.

Expanding the analysis of pedestrian injury and mortality risk to other vehicle shapes indicates that vans, pickups, and SUVs are, mile for mile, more likely to be involved in a collisions resulting in a pedestrian fatality than a passenger cars (Paulozzi, 2005). This study calculated the risk of pedestrian fatalities for different types of motor vehicles using miles travelled as a measure of exposure.

Table 1: Sampling frames, study design and additional information

Author, Year, Country	**Sample, method/design and analysis**		**Reference group**	**Additional information on analysis**
L,J, Paulozzi, 2005, USA	Observational study, 2002 data, sample of 4875 pedestrians killed	Relative risk of death by vehicle type per billion vehicle miles	-	-
B,S, Roudsari et al, 2004, USA	Crash data, Observational study, 542 pedestrians involved in collisions with vehicles	Pedestrians killed by different vehicle types	Surviving pedestrians	LTV and Van vehicle shapes only
B,Y, Heanry, 2003, USA	Crash data, Observational study, pedestrian fatalities and injuries by vehicle type. Sample of 388 pedestrians.	Pedestrians killed and injured	Surviving pedestrians and those with lower injury severities	Results split by speed limit bands
M,F, Ballesteros, 2002, USA	Crash data, Observational study, pedestrian fatalities and injuries by vehicle type.	Pedestrians killed and injured ISS ≥16	Surviving pedestrians and those injured to ISS <16	SUV/Pickup and Van vehicle shapes

2.2 DESCRIPTION OF AVAILABLE STUDIES

Studies investigate the subject of vehicle shape through observational, case-controlled studies based on real world collision data. Injury severity results are generally provided as an Odds Ratio (OR) or Relative Risk (RR) through simple bivariate or multivariate associations. Where made, adjustments for associations or variables of interest are through logistic regression analysis.

Most studies focussed on the vehicle types of Light trucks/Pickups (LTVs/PUs) and Sports Utility Vehicles (SUVs). A wide range of results have been reported with the overall conclusion that, compared to conventionally designed passenger vehicles, these vehicle types represent a more aggressive impact for pedestrians and consequently a greater risk of severe or fatal injuries in a collision.

2.3 VOTE COUNT FOR VEHICLE SHAPE

Three of the four papers analysed provided statistically significant results which indicate that some vehicle shapes are correlated with more severe injuries and deaths than others. In the other paper the same trend is evident however the results for some vehicle types are not statistically significant. One conclusion that could be drawn, if taking an overview of the papers as a whole, could be that the hypothesis of more aggressive vehicles causing higher injury severities is true; however the individual effects reported may indicate something else.

The table below shows a vote count analysis for the four vehicle shape papers. A vote count analysis is in effect answering the simple question: 'is there any evidence of an effect of vehicle shape on road safety?' This question is answered by counting the results of the sign test in the effects column (table 1); a larger number of 'votes' shown by an ↗ indicating a risk to road safety compared to fewer 'votes' shown by a ↘ indicating a lesser risk to road safety will indicate that there is greater risk of severe or fatal injuries in a collision with more aggressive vehicle shapes.

Analysing the number of effects indicates that 41% (n=7) show greater risk of sever or fatal injury in the event of a collision. The same proportion is evident for non-statistically significant results or results which do not show a strong association with severe of fatal injuries. 3 effects (17%) show that the risk of more severe injuries is lessened.

Overall using information from the vote count it is still possible to conclude that there is a risk of increasing pedestrian injuries and fatalities by aggressive vehicle shape although some of the measures, despite showing similar results, are not statistically significant.

The vote count process has been conducted using best practice where possible; this entails using a sign test (table 1) and ensuring studies that show 'harm' are compared with a number showing 'benefit', regardless of the statistical significance or size of their results. Additionally no subjective decision has been made on assigning non-statistically significant results to either the 'harm' or 'benefit' counts.

Table 2: Summary of study results: Vote count analysis

Outcome definition*	Tested in number of studies	Result (number of studies)			Result (% of studies)			Result (number of effects)			Result (% of effects)		
		↑	-	↓	↑	-	↓	↑	-	↓	↑	-	↓
Injury severity*	4	3	1	-	75%	25%	-	7	7	3	41%	41%	17%

*outcome for all studies is in terms of injury severity or fatality.

Table 3: Study results: overview of characteristics and effects for coded studies

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome -description
L,J, Paulozzi, 2005, USA	Collision with Motorcycle	Fatality	↗	RR=1.93, CL=95%, CI=1.30-2.86	Significant increase in risk of Motorcycle killing a pedestrian per billion miles than passenger car
	Collision with Bus	Fatality	↗	RR=7.97, CL=95%, CI=6.33-10.04	Significant increase in risk of Bus killing a pedestrian per billion miles than passenger car
	Collision with Light Truck	Fatality	↗	RR=1.45, CL=95%, CI=1.37-1.55	Significant increase in risk of light truck killing a pedestrian per billion miles than passenger car

	Collision with Heavy Truck	Fatality	↗	RR=0.96, CL=95%, CI=0.79-1.18	Significant increase in risk of heavy truck killing a pedestrian per billion miles than passenger car
	Collision with combination Truck	Fatality	↗	RR=0.86, CL=95%, CI=0.73-1.01	Significant increase in risk of combination truck killing a pedestrian per billion miles than passenger car
B,S, Roudsari et al, 2004, USA	Collision with LTV	Fatality	↗	OR=3,4, CL=95%, CI=1.4-7.8	Significant increase in risk of LTV killing a pedestrian compared to passenger car
	Collision with Van	Fatality	↘	OR=0.6, CL=95%, CI=0.1-2.2	Significant decrease in risk of Van killing a pedestrian compared to passenger car
B,Y, Heanry, 2003, USA	Collision with LTV at <30km/h	Fatality	↗	OR=3.34, CL=95%, CI=1.35-8.29	Significant increase in risk of LTV killing a pedestrian compared to passenger car
	Collision with LTV at <30km/h	ISS ≥ 16	↗	OR=2.13, CL=95%, CI=1.10-4.16	Significant increase in risk of LTV injuring a pedestrian ISS ≥ 16 compared to passenger car
	Collision with LTV at <30km/h	MAIS > 2	↗	OR=1.87, CL=95%, CI=0.95-3.68	Significant increase in risk of LTV injuring a pedestrian MAIS > 2 compared to passenger car
	Collision with LTV at >30km/h	Fatality	-	OR=1.13, CL=95%, CI=0.60-2.13	Non-significant increase in risk of LTV killing a pedestrian compared to passenger car
	Collision with LTV at >30km/h	ISS ≥ 16	-	OR=0.92, CL=95%, CI=0.49-1.73	Non-significant decrease in risk of LTV injuring a pedestrian ISS ≥ 16 compared to passenger car
	Collision with LTV at >30km/h	MAIS > 2	-	OR=5.23, CL=95%, CI=0.53-51.41	Non-significant increase in risk of LTV injuring a pedestrian MAIS > 2 compared to passenger car
M,F, Ballesteros, 2002, USA	SUV/Pickup	Fatality	-	OR=1.32, CL=95%, CI=0.92-1.87	Non-significant increase in risk of SUV/Pickup killing a pedestrian compared to passenger car
	Van	Fatality	-	OR=1.30, CL=95%, CI=0.78-2.15	Non-significant increase in risk of Van killing a pedestrian compared to passenger car
	SUV/Pickup	ISS ≥ 16	-	OR=1.15, CL=95%, CI=0.86-1.55	Non-significant increase in risk of SUV/Pickup injuring a pedestrian ISS ≥ 16 compared to passenger car
	Van	ISS ≥ 16	-	OR=1.63, CL=95%, CI=1.10-2.42	Non-significant increase in risk of van injuring a pedestrian ISS ≥ 16 compared to passenger car

↗ = *Significantly greater risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).*

↘ = *Significantly less risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).*

- = *Differences in accident rates/injury risk may have been found, but not statistically significant.*

2.4 CONCLUSION

Studies on the effect of vehicle shape on road safety focused on the outcomes of pedestrian injury severity and fatalities. Studies reporting these outcomes found that in impacts with vehicles that fit the general body shape of Sports Utility Vehicles (SUV's) and Pick-ups (light trucks) pedestrians were more likely to have more severe injuries and more likely to die than in collisions with conventional passenger vehicles. In addition it is also possible to say that vehicles with this body shape are more likely to kill or injure a pedestrian per billion vehicle miles compared to conventional cars.

At present there are a limited number of studies available for analysis and those that are available all use North American data from real world crashes. Although a lot of research has been devoted to the effects of vehicle shape countermeasures, such as finite element analysis modelling for new vehicle designs and detailed analysis of vehicle structural performance, there is still scope for more work to be conducted into the investigation of real world effects and risks in this topic. This is particularly relevant with respect to the situation in Europe where vehicle fleets can differ significantly from North America.

3 Supporting Document

3.1 METHODOLOGY

Literature Search strategy

Literature search was conducted in May 2016. It was carried out in two databases with broadly similar search strategies. The following databases were browsed through during the literature search: 'Scopus' and 'TRID'. The same search was conducted for both PTW and pedestrian road user types so the following information is shown for both; final numbers are only shown for the specific road user relevant for this synopsis. Detailed search terms, as well as their linkage with logical operators and combined queries are shown in the following tables:

Search no.	Search terms / operators	Hits
#1	"vehicle design" OR "vehicle model" OR "vehicle style" OR "vehicle category" OR "vehicle type" OR "vehicle ergonomics" OR "vehicle aesthetics" OR "vehicular gadgetry" OR "dashtop device*" OR "HMI" OR "Human machine interface" OR "visor" OR "windscreen"	25,624
#2	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	643,086
#3	"risk*" OR "severity" OR "frequency"	5,889,383
#4	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mofa*"	12,623
#5	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	233,162
#1 AND #2 AND #3 AND #4	All years	53
#1 AND #2 AND #3 AND #5	All years	107

After excluding the papers before 1990, we conclude in the following:

Design-PTW *: 41 – Not included in final PTW search*
Design-Pedestrians: 98

Search no.	Search terms / operators	Hits
#1	"vehicle design" OR "vehicle model"	15,000
#2	"vehicle style" OR "vehicle category" OR "vehicle type" OR "vehicle	2328

	ergonomics" OR "vehicle aesthetics"	
#3	"vehicular gadgetry" OR "dashtop device*" OR "HMI" OR "Human machine interface" OR "visor" OR "windscreen"	1203
#1 OR #2 OR #3 (referred to as #4)		18200
#5	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	15,000
#6	"risk*" OR "severity" OR "frequency"	15,000
#7	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mofa*"	9919
#8	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	15,000
#4 AND #5 AND #6 AND #7	All years	47
#4 AND #5 AND #6 AND #8	All years	99

After excluding the papers before 1990, we conclude in the following:

Design-PTW : 46 – *Not included in final PTW search*
Design-Pedestrians: 99

	Design pedestrian
Total number of studies to screen title/ abstract	197
-De-duplication	4
-Not relevant studies excluded	25
-Studies with no risk estimates excluded	67
Studies not clearly relevant to the topic (full-text screening later)	87
Remaining studies	14
Studies to obtain full-texts	4

Prioritizing Step A (most recent studies)
Prioritizing Step B (Journals over conferences and reports)

No meta-analyses were found

Initial screening involving de-duplication, removal of non-relevant studies and other studies showing no clear risk estimates resulted in 87 remaining studies. These were screened more thoroughly using abstracts to determine whether they could be used for this synopsis. In total a further 73 were removed at this stage for similar reasons identified above, for example, non-relevance or lack of risk estimates but also due to foreign language text or lack of statistical robustness. In total full text were available for 14 studies of which four were fully coded and are the focus of this synopsis.

3.2 CODED STUDIES

1) Henary, B. Y., Crandall, J., Bhalla, K., Mock, C. N., & Roudsari, B. S. (2003, September). Child and adult pedestrian impact: the influence of vehicle type on injury severity. In Annu Proc Assoc Adv Automot Med (Vol. 47, pp. 105-26).

2) Ballesteros, M. F., Dischinger, P. C., & Langenberg, P. (2004). Pedestrian injuries and vehicle type in Maryland, 1995–1999. Accident Analysis & Prevention, 36(1), 73-81.

3) Roudsari, B. S., Mock, C. N., Kaufman, R., Grossman, D., Henary, B. Y., & Crandall, J. (2004). Pedestrian crashes: higher injury severity and mortality rate for light truck vehicles compared with passenger vehicles. Injury Prevention, 10(3), 154-158.

4) Paulozzi, L. J. (2005). United States pedestrian fatality rates by vehicle type. Injury prevention, 11(4), 232-236.

Pedestrian - Low NCAP rating

1 Summary

Reed S., Loughborough University, September 2016

1.1 COLOUR CODE: YELLOW

International literature indicates that in a collision between a pedestrian and a low scoring pedestrian NCAP vehicle there exists a significantly increased risk of more severe pedestrian injuries and an overall poorer long term injury outcomes compared to high performing EuroNCAP cars.

1.2 KEYWORDS

Pedestrian, Euro NCAP, Car, Pedestrian Protection, Pedestrian testing, Injury

1.3 ABSTRACT

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the passive crash performance of the vehicle in a collision. This passive performance can be measured and compared by using the European new car assessment program (EuroNCAP) score. By comparing injury outcomes from real world collision data and the EuroNCAP score of the striking vehicle it has been estimated that the effect of being hit by a vehicle which scores just one point more than a comparative vehicle through the EuroNCAP pedestrian testing regime relates to a 1% decrease in risk of serious injury. This rises to 2.5% decrease in risk of fatality per additional EuroNCAP point.

The most important point to emphasise with this topic is that there is currently a significant limitation to the analysis as the very best performing vehicles as tested by EuroNCAP feature less commonly in the general vehicle fleet. This effect is only seen with the very latest vehicles with potentially the highest pedestrian test scores as there will be latency in the system between a particular vehicles NCAP assessment and being seen in sufficient numbers on the roads to feature in collision data. Potential issues may occur when drawing conclusions on this type of vehicle as the collision statistics do not support robust conclusions. In addition the effect of high impact speeds (>50kph) are less well understood as this is above the limits of current testing (currently 40kph for head and upper and lower leg impact tests). As such pedestrian kinematics, Impact locations and crush pattern are likely to be different to that seen in testing and possibly beyond the performance limits of vehicles designed to meet testing limits.

In addition it is important to understand how EuroNCAP scores are derived. Scores awarded to vehicles are not directly comparable between different vehicles or over time. For example a vehicle that scored 5 EuroNCAP stars will only be broadly comparable between its direct competitors and will not be comparable to vehicles manufactured earlier or later that also score 5 stars. The main reason for this is that the NCAP tests evolve to include more stringent requirements; vehicles tested five years ago, despite scoring 5 stars in period, are not comparable with 5 star vehicles tested today as the threshold for scoring has changed. The studies included cover data collections periods between 4 and 14 years (all between 2003 and 2014) so the effect of evolving testing protocols may be evident.

Although not affecting the pedestrians testing to the same degree, the test protocol in full scale crash testing results in vehicles that are only measured against themselves, in effect this results in a crash test vehicle hitting itself in frontal and side impacts. This test design means that a vehicle's 5 star score is only comparable with other vehicles in its group. (Supermini vs supermini as opposed to supermini vs large family car).

1.4 BACKGROUND

What is a low EuroNCAP score?
All new vehicles assessed by EuroNCAP undergo a series of tests to determine their overall crashworthiness; this can be split into four different categories, one of these being an assessment of pedestrian safety. Generally the assessment of a low EuroNCAP score has some similarities with the vehicle shape synopsis but is overlaid with a more technical assessment on how individual elements of the vehicle perform when in collision with a pedestrian (or other vulnerable road user). A low score can be as a result of poor performance of the vehicles bonnet surface, leading edge of bonnet, windshield and/or bumper which will be identified as potential risks, and therefore injuries, to pedestrian head, pelvis, upper and lower legs. Assessments are available for most mass produced passenger vehicles and some small to medium sized commercials.

How do low EuroNCAP scores effect road safety?
Vehicles that score poorly in EuroNCAP pedestrian assessments effect road safety as they can present a much lower level of protection to a pedestrian (or other vulnerable road user) in the event of a collision.

Which safety outcomes are affected by a low EuroNCAP score?
In the international literature, the effect of vehicle shape on pedestrian safety has been measured mainly on one basic outcome, namely injury outcome. This can be in terms of fatalities or other injury outcomes such as risk of serious consequences (RSC).

How is the effect of number of low EuroNCAP score studied?
International literature shows that the effect of Low EuroNCAP score on road safety is usually examined by analysis of real world collision data. An analytical approach links pedestrian injuries to each individual car model with the cars divided into groups depending on their rating score, the groups of cars can then be compared with regards to injury severity outcome. Injury severity results are generally provided as relative difference in injury severity or risk of serious consequences between groups of cars. The studies identified all used data from European member states, two from Sweden and one from Germany. Certain selections and/or conditions are applied to the data, for example fatalities occurring at the scene are not included as data was drawn from hospital admissions and these did not show in the sample. Additionally a limit of 50kph has been applied to impact speed as this has previously been shown to be above EuroNCAP testing protocols.

1.5 OVERVIEW RESULTS

All studies indicate that there is a significant difference between injury outcomes for a pedestrian struck by a low scoring EuroNCAP vehicle and a high scoring EuroNCAP vehicle. A collision between a pedestrian and a low scoring EuroNCAP vehicle significantly influences pedestrian injury severity, leading to poorer injury outcomes compared to high performing EuroNCAP cars.

1.6 NOTES ON ANALYSIS METHODS

In general, the coded studies are of sufficient quality and are methodologically sound, there are however a limited number of studies from which to form the synopsis; this is predominantly due to the relatively recent inception of high scoring pedestrian EuroNCAP vehicles. All studies used relatively large samples in-keeping with the use of large scale real world data sets and research was mostly carried out in European Member states of Germany and Sweden. Overall, the topic has only relatively recently been covered and at present only 3 studies could be found. Providing the pattern of studies increases in a similar way to comparisons between occupant protection and EuroNCAP score then it is likely that the knowledge in this subject area will continue to evolve.

2 Scientific Overview

2.1 LITERATURE REVIEW

From the studies identified in the international literature it seems that Pedestrian EuroNCAP score has an overall significant impact on the outcome of pedestrian impacts. All studies analysed show that pedestrian injuries and fatalities are significantly affected by an impact with a vehicle scoring poorly in EuroNCAP testing as opposed to a car scoring well in EuroNCAP testing.

Strandroth et al (2011) analysed 488 car to pedestrian impacts between 2003 and 2010 which showed a significant reduction of injury severity for cars with better pedestrian scores. The injury reduction was expressed in terms of percent of medical impairment through mean risk of serious consequences (mRSC) at 1%, 5% and 10% limits and showed that the relative difference between medium-performing cars and low-performing cars was 17%, 26%, and 38%. A similar relative difference was also reported for AIS 2+ injured pedestrians with a difference reported of 17% between medium-performing cars and low-performing cars. The analysis included AIS 3+ injuries but the result was not statistically significant owing to the potential for pedestrian protection being eroded as higher severity and higher speed impacts are encountered. One limit of this study was the lack of very high performing vehicles which were too few in number to form robust conclusions.

Pastor (2013) analysed German collision data between 2009 and 2011 with large sample sizes to determine that there was a significant correlation between Euro NCAP pedestrian score and injury outcome in real-life car to pedestrian crashes. This is the only study that considered fatalities and concluded that the probability of a pedestrian getting fataly injures was reduced by 35% if hit by a vehicle scoring 22 pedestrian NCAP points as compared to a vehicle scoring 5 pedestrian NCAP points. A similar result is reported for serious injuries where a percentage change of 16% is seen between high scoring EuroNCAP vehicles and low scoring EuroNCAP vehicles. In conclusion the analysis lays out a 'rule of thumb' which states that for each additional NCAP point a relative reduction in probability of 2.5% can be predicted for fatalities, and 1% for serious injuries and that if all cars in the German fleet were high scoring pedestrian NCAP vehicles the estimated reduction potential for fatalities was 9% and 6% for serious injuries.

Strandroth et al (2014) analysed collisions between 2003 and 2014 involving 1184 pedestrians drawn from Swedish STRADA database. In general, when comparing poor performing vehicles to medium performing vehicles or medium performing vehicles to high performing vehicles, results indicate that significant reductions in injury severity can be expected as pedestrian NCAP ratings increase. These results are statiscally significant for all levels of injury (MAIS 2+, RPMI1+ and RPMI10+) with the exception of MAIS3+ due to a small sample size (results not reported). The study, despite its large sample size indicates a number of potential biases, such as the effect of driver sex and age, pedestrian and bicyclist age and sex as well as road environment (characteristics like speed limit, light conditions and road state).

Table 10: Descriptions of coded studies on Low NCAP

Author, Year, Country	Sample, method/design and analysis		Reference group	Additional information on analysis
C, Pastor, 2013, Germany	Crash data, Observational. Relative difference between proportions of casualties by vehicle NCAP scores – sample of 27,143 cases.	Proportion of pedestrians killed or seriously injured by poor performing vehicles	Proportion of pedestrians killed or seriously injured by good performing vehicles	Only accidents involving one passenger car and one pedestrian aged between 6 and 64.
J, Strandroth et al, 2011, Sweden	Crash data, Observational. Relative difference between pedestrian injuries by vehicle NCAP score – sample of 488 pedestrians.	Proportion of pedestrians seriously injured by poor performing vehicles	Proportion of pedestrians seriously injured by good performing vehicles	Only pedestrians hit by the front of vehicles on roads with speed limit up to 50 km/h included.
J, Strandroth et al, 2014, Sweden	Crash data, Observational study, Relative difference between pedestrian injuries by vehicle NCAP score - Sample of 1184 pedestrians.	Proportion of pedestrians seriously injured by poor performing vehicles	Proportion of pedestrians seriously injured by good performing vehicles	Only pedestrians hit by the front of a car tested by Euro NCAP were included.

2.2 RESULTS

Overall there was strong homogeneity between the overall paper conclusions and each individual effect as can be seen in the following table, as such it is not necessary to conduct a vote count analysis for this topic.

Table 1: Main outcomes of coded studies on Low NCAP

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
C, Pastor, 2013, Germany	Pedestrian in collision with poor performing vehicle	Serious injury	↗	35% (percentage change)	Significant increase in risk of low performing vehicle injuring a pedestrian compared to high performing vehicle
	Pedestrian in collision with poor performing vehicle	Fatality	↗	16% (percentage change)	Significant increase in risk of low performing vehicle killing a pedestrian compared to high performing vehicle
J, Strandroth et al, 2011, Sweden	Pedestrian in collision with poor performing vehicle	AIS 2+ injuries	↗	-17% (Relative difference)	Significant increase in risk of low performing vehicles injuring a pedestrian compared to high performing vehicles
	Pedestrian in collision with poor performing vehicle	AIS 3+ injuries	-	-28% (not statistically significant)	Non-significant increase in risk of low performing vehicles injuring a pedestrian compared to high performing vehicles
	Pedestrian in collision with poor performing vehicle	mRSC 1%+	↗	-17% (Relative difference)	Significant increase in risk of low performing vehicles injuring a pedestrian compared to high performing vehicles

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome - description
	Pedestrian in collision with poor performing vehicle	mRSC 5%+	↗	-26% (Relative difference)	Significant increase in risk of low performing vehicles injuring a pedestrian compared to high performing vehicles
	Pedestrian in collision with poor performing vehicle	mRSC 10%+	↗	-38% (Relative difference)	Significant increase in risk of low performing vehicles injuring a pedestrian compared to high performing vehicles
J, Strandroth et al, 2014, Sweden	Pedestrian collision with car	mRPMI1 between poor and medium performing vehicles	↗	-18% (Relative difference)	Significant increase in risk of poor performing vehicles injuring a pedestrian compared to medium performing vehicles
	Pedestrian collision with car	mRPMI1 between medium and good performing vehicles	↗	-24% (Relative difference)	Significant increase in risk of medium performing vehicles injuring a pedestrian compared to good performing vehicles
	Pedestrian collision with car	mRPMI10 between poor and medium performing vehicles	↗	-37% (Relative difference)	Significant increase in risk of poor performing vehicles injuring a pedestrian compared to medium performing vehicles
	Pedestrian collision with car	mRPMI10 between medium and good performing vehicles	↗	-56% (Relative difference)	Significant increase in risk of medium performing vehicles injuring a pedestrian compared to good performing vehicles
	Pedestrian collision with car	% MAIS 2+ between poor and medium performing vehicles	↗	-8% (Relative difference)	Significant increase in risk of poor performing vehicles injuring a pedestrian compared to medium performing vehicles
	Pedestrian collision with car	% MAIS 2+ between medium and good performing vehicles	↗	-20% (Relative difference)	Significant increase in risk of medium performing vehicles injuring a pedestrian compared to good performing vehicles

↗ = *Significantly greater risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).*
↘ = *Significantly less risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).*
- = *Differences in accident rates/injury risk may have been found, but not statistically significant.*

2.3 CONCLUSION

Studies on the effect of low NCAP score on road safety identified in the international literature focused on pedestrian injury severity and fatality. Studies of this type mostly show a higher injury risk or fatality risk for low performing vehicles although at the upper end of the spectrum, with very high scoring NCAP cars, there are too few numbers in the crash population to form robust results.

Summarizing, low pedestrian EuroNCAP cars lead to more severe accidents measured as an increase in injury severity or fatalities compared to high scoring pedestrian EuroNCAP cars. In order to fully exploit this result it is necessary to understand the two major caveats, firstly that there is only a small proportion of the very best performing pedestrian NCAP vehicles in the sample and secondly the limitations imposed on the data by the changing NCAP protocols which make comparisons of NCAP scores over time problematic and potentially misleading.

3 Supporting Document

3.1 METHODOLOGY

Literature Search strategy

Literature search was conducted in May 2016. It was carried out in two databases with broadly similar search strategies. Following databases were browsed through during the literature search: 'Scopus' and 'TRID'. Detailed search terms, as well as their linkage with logical operators and combined queries are shown in the following tables:

Database: Scopus **Search Date**: 04/05/2016

Search no.	Search terms / operators	Hits
#1	"EuroNCAP" OR "safety rating" OR "electric vehicles" OR "special vehicle" OR "ATV" OR "all-terrain vehicle*" OR "quad bike*" OR "regulation*" OR "functional safety"	1,708,344
#2	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	643,086
#3	"risk*" OR "severity" OR "frequency"	5,889,383
#4	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mota*"	12,623
#5	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	233,162
#1 AND #2 AND #3 AND #4	All years	81
#1 AND #2 AND #3 AND #5	All years	110

After excluding the papers before 1990, we conclude in the following:

General-PTW : 73
General -Pedestrians: 106

Database: TRID **Search Date**: 11/05/2016

Search no.	Search terms / operators	Hits
#1	"EuroNCAP" OR "safety rating" OR "electric vehicles" OR "special vehicle"	7033
#2	"ATV" OR "all-terrain vehicle*" OR "quad bike*"	675
#3	"regulation*" OR "functional safety"	15000

#1 OR #2 OR #3 (referred to as #4)		22463
#5	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	15000
#6	"risk*" OR "severity" OR "frequency"	15000
#7	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mota*"	9919
#8	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	15000
#4 AND #5 AND #6 AND #7	All years	22
#4 AND #5 AND #6 AND #8	All years	52

After excluding the papers before 1990, we conclude in the following:

General-PTW : 22
General-Pedestrians: 52

PTW papers accounted for 87; removed from this search to show results only for Design-General search:

	Design-General
Total number of studies to screen title/ abstract	153
-De-duplication	2
-Not relevant studies excluded	66
-Studies with no risk estimates excluded	39
Studies not clearly relevant to the topic (full-text screening later)	
Remaining studies	46
Studies to obtain full-texts	

Prioritizing Step A (most recent studies)
Prioritizing Step B (Journals over conferences and reports)

No meta-analyses were found.

3.2 REFERENCES

1) Pastor, C. (2013) Correlation between Pedestrian Injury Severity in Real-Life Crashes and Euro NCAP Pedestrian Test Results. ESV.

2) Strandroth, J., Rizzi, M.,Sternlund, S,. Lie, A., Tingvall, C. (2011) The Correlation Between Pedestrian Injury Severity in Real-Life Crashes and Euro NCAP Pedestrian Test Results. Traffic Injury Prevention. 12:604–613,

3) Strandroth, J., Sternlund, S., Lie, A., Tingvall, C., Rizzi, M., Kullgren, A., Fredriksson, R. (2014). Correlation between Euro NCAP Pedestrian Test Results and Injury Severity in Injury Crashes with Pedestrians and Bicyclists in Sweden. Stapp Car Crash Journal, Vol. 58, p. pp 213–232.

PTW -
Accident Characteristics

1 Summary

Reed S., Loughborough University, September 2016

1.1 COLOUR CODE: GREY

International literature indicates that there is a diverse range of risks presented to powered two wheeler users when using the public highway. In general the topic of powered two wheelers is not as widely studied as that of passenger vehicle occupants or vulnerable road users limiting transferability and generalizability This topic covers a range of studies which have be coded to illustrate a range of risks presented to powered two wheeler users.

1.2 KEYWORDS

Powered two wheeler, PTW; Pedestrian; Engine size; Speed; Injury; age; experience

1.3 ABSTRACT

Powered two wheeler accident characteristics encapsulate a range of different features which have been documented through real world crash data for accidents involving PTWs. Compared to passenger vehicles there are comparatively few in depth studies investigating the features of PTW crashes and fewer still that study the same features, this poses problems with identifying characteristics that do exist in PTW collisions and makes it necessary to consider a diverse range of PTW crash studies together as one topic, the benefit of this approach will be to reveal where PTW users are exposed to a greater risk of injury or mortality. It was found that overall and within this wide range of topics that young PTW users and those with limited experience of a particular PTW are at increases risk of injury or death, additionally greater engine size and travel speeds over the posted speed limit also increase the risks to PTW users. The effect of PTW use on vulnerable groups such as pedestrians was also covered showing that PTWs are at a higher risk of hitting pedestrians than 4 wheeled vehicles. The approach of combining varied studies into one synopsis presents difficulties for statistical power, generalizability and transferability as there will be a limited amount of information about each individual characteristic.

1.4 BACKGROUND

What are PTW accident characteristics and what is the impact on road safety?

This synopsis identifies five main characteristics related to PTW accidents. For each of these, a brief outline of the characteristic, followed by its known general impact on road safety, is given.

Travel speed at time of a PTW crash and associated risk of sustaining an injury
In the field of vehicle crashworthiness it can be demonstrated that, for all road user types, injury severity correlates with collision speed; this outcome is as a result of physical laws and will remain unchanged unless the speed change experienced by the road user is managed in some way. This topic covers the effect of injury outcome on PTW riders, specifically their speed behaviour in respect to the posted speed limit i.e. whether at the time of their crash they were travelling under, over or at the posted speed limit. No reference is made to the actual travel speed at which the collision took place as this brings in a range of uncontrolled variables, for example a high speed road can afford

either good protection (a motorway for example) or poor protection (a rural road) for the same speed limit. Characteristics in the literature show a significant increase in mean injury severity score for PTW riders travelling at or above the posted speed limit compared to those travelling below the posted speed limit.

Age and associated risk of sustaining an injury in a PTW crash
A major pillar of road safety is based on the premise that older road users are generally safer than younger road users. This conclusion is consistent through almost all road user types and is used internationally as a key component of licensing restrictions aimed at reducing the injury burden from road traffic crashes. The major outcome measures of crashes with PTW users of differing ages are identified through hospital admissions or collision data. These accident characteristics show that the odds of an older PTW user attending a hospital emergency department with serious injuries is significantly less than young PTW riders.

Riding experience and risk of sustaining an injury in a PTW crash
In a similar way to the age restrictions imposed on young PTW riders the use of experience as a way of reducing risk is also used internationally. Experience can be based on a number of different and discreet variables, for example practicing PTW control over a long duration but covering limited distance or they can be combined into one more general period of learning, for example a PTW rider may be required to undertake a certain amount of riding before progressing to bigger, more powerful machines. Characteristics seen in collision data indicate that more severe injuries and fatalities will be evident in samples of riders using a PTW that they have little experience of (<1000km ridden on that PTW) compared to riders on a PTW they know well (≥10,000km ridden on that PTW). This outcome is measured in terms of total km ridden on a particular machine and does not differentiate between regular use over one year or sporadic use over many years i.e. this metric is not km/year or km/month but rather km/PTW ownership.

Engine size and risk of sustaining an injury in a PTW crash
Possibly the most common way internationally of managing a reduction in the injury burden from road traffic crashes is the application of engine size or power limits to motorcycles for learner or less experienced PTW users. Engine size in itself is a relatively crude measurement of both the power and/or performance of a particular PTW however it is easy to determine and regulate for. Engine size is commonly, although not exclusively measured in cubic capacity (cc) – a larger number indicates a greater engine size and a likely increase in power. PTW manufacturers build engines with a wide range of cubic capacities, however there are normally some common 'steps' to this measurement; these steps can usually be seen in any studies where banding has been applied to the engine size categories. In terms of outcomes, the impact on road safety of larger PTW engine sizes will be more severe injuries and fatalities to PTW users.

PTW Collisions with pedestrians in urban environments
As urban environments become more congested across the world it is commonplace to see PTW being used for urban journeys. In some southern parts of Europe, countries surrounding the Pacific Rim and in India and China there is extensive use of motorcycles in urban environments, this fleet density combined with an increased number of pedestrians and other vulnerable road users will inevitably increase conflict points and collisions. The risk of a PTW hitting a pedestrian in town can also be elevated with uncontrolled pedestrian crossing behaviours such as crossing between queuing or slow moving traffic where a traditional PTW may still be able to travel at an elevated speed. Combined with the overall visual presence of a PTW, being as they are narrow and able to position themselves in a variety of places on the road can make the more difficult to identify from a pedestrians viewpoint. The effect on road safety of a PTW being used in an urban environment will lead to a higher risk of a PTW hitting and injuring a pedestrian than for four-wheeled vehicle drivers.

Which safety outcomes are affected by PTW collisions?

In the international literature, the effect of PTW accident characteristics on road safety has been measured mainly on one basic outcome, namely injury outcome. This can be in terms of fatalities or other injury outcomes and for different road user groups, for example the rider, passengers/pillions or pedestrians. Often, but not always this injury outcome is expressed as a rate, i.e. injuries or fatalities per million/billion vehicle miles/kilometres.

How are PTW accident characteristics studied?

In general accident characteristics of the type studied for this topic are derived from real world collision data from a range of sources (national databases, police reports, hospital admissions etc.), this method is very well understood and extensively used providing that sample sizes are large and adequate selection criteria applied, in keeping with this all studies analysed used real world collision data. Three of the four studies used real world data drawn from hospital admission information which provides some additional controls for underreporting. In addition, and in keeping with the study design, two of these studies collected data from a control group (i.e. not directly involved in a PTW crash) from road side surveys on comparable road types. The three studies that used real world data were from the Asia-Pacific area, specifically Australia and New-Zealand. In all cases certain selections have been applied to the data, for example ensuring that riders reporting to hospital were injured to a severe enough level or that the collision took place on the public highway. One study used real world collisions data collected from police reports to compare PTW and pedestrian collisions with 4 wheeled vehicle and pedestrian collisions.

1.5 OVERVIEW RESULTS

All studies combine to indicate that there are significant and varied characteristics of PTW rider crashes. The results show that for most cases the injury outcome for PTW riders is made worse by the characteristics identified to that expected by a four wheel user in the same circumstances i.e. a young inexperienced driver may suffer less severe injuries in a crash due to the protective effect of the vehicle compared to a young and inexperienced PTW user. Summarising, the results indicate that a young rider riding an unfamiliar PTW with a large engine at or above the posted speed limit and in the presence of pedestrians will present a much higher risk of injury or mortality than an older experienced rider on a familiar PTW with a small engine below the speed limit and away from pedestrians.

1.6 NOTES ON ANALYSIS METHODS

In general, the coded studies are of sufficient quality and are methodologically sound, there are however a limited number of studies on each individual topic from which to form a synopsis; this is predominantly due to the lack of consistent research for PTW users as compared to four wheeled vehicle users. All studies used relatively large samples where practical in-keeping with the use of large scale real world data sets. Overall, the topic shows some significant results and highlights a range of risks presented to users of PTWs however there is not the weight of studies behind each sub-topic from which to make very strong conclusions.

2 Scientific Overview

2.1 LITERATURE REVIEW

From the studies identified in the international literature it appears that there are a number of significant risks associated with PTW users which can have an effect on overall road safety. The studies covered below all show risks in terms of injury or fatalities but the topic of the risk is varied as covered in the 'background' section of the synopsis.

Langley et al (1999) investigated whether an increase in motorcycle engine capacity has a corresponding increase in moderate and fatal injuries. The study design was case-controlled; cases were drawn from hospital admissions as a result of real world PTW crashes and controls from road side surveys and follow up interviews. Motorcycle engine capacities were measured in cubic capacity (cc) and banded roughly equally but also designed to reflect the common engine sizes manufactured. Results are presented as an odds ratio for each engine size category with <250cc used as the reference, these were adjusted for confounding factors such as young age, male riders, exceeding speed limit and alcohol consumption. After adjustment all engine capacities show an increase in risk (with the exception of 250cc to 499cc) however none are statistically significant. In conclusion it was suggested that there was no consistent patter between an increased engine capacity and an increased risk but that this may be due to cubic capacity being a relatively poor representation of PTW performance.

Mullin et al (2000) assessed whether there were associations between experience and PTW related injury. The study used a large dataset of real world PTW collisions in New Zealand as reported to hospital emergency departments which was compared to controls in the form of interview information from PTW road side surveys. In total 1696 PTW users were included in the study (463 controls and 1233 cases) with results showing that young riders and users who were inexperienced with a particular motorcycle at much higher risk of injury than older and more experienced riders. The study surveyed a wide range of ages of PTW uses but found that riders who were aged less than 25 were around 50% more likely to be involved in an injury accident as riders aged 25 years or older. In addition the experience of a particular PTW, and not necessarily experience of PTW use in general was associated with a reduction in risk with riders who had ridden their PTW for more than 10,000km at a much lower risk of injury collision than riders who had only covered 1000km on a particular PTW.

Cunningham et al (2012) analysed data from a large number of real world PTW crashes in Australia to determine whether vehicle speed relative to posted speed limit at the time of the crash influences the overall injury outcome of the PTW user. The study used nearly 1700 individual PTW users who were admitted to hospital as a result of a PTW crash and recorded both their mean Injury Severity Score (ISS) score and whether they were travelling below the speed limit, above the speed limit or at the speed limit at the time of the crash. Results showed that there was a significant absolute difference between mean ISS scores in the 'below limit' group compared to both the 'at' and 'above' speed limit groups suggesting that there is an increased risk associated with speed behaviour relative to speed limits irrespective of absolute speed at impact.

Clabaux et al (2014) investigated a relatively small number of police reported crashes involving pedestrians in urban settings, the aim being to understand whether PTW users were more at risk of hitting a pedestrian that other 4 wheeled vehicle users. The study used police reported crash information and traffic survey data from 9 urban sites thereby allowing results to be reported in terms of increased risk by proportion of the traffic volume. Results show that on average between the investigation sites the risk of a PTW hitting a pedestrian was approximately three times higher (OR=3.06, CL=95%, CI=2.26-4.14) compared to all four wheel vehicles and marginally higher when comparing to passenger cars only (OR=3.12, CL=95%, CI=2.29-4.24). Due to the small sample size of both study locations and subsequent collisions, combined with the lack of other studies looking specifically at this topic, makes robust and saleable conclusions difficult however the result in isolation suggests that there is an increased risk of PTW users hitting pedestrians in urban environments over 4 wheeled vehicle types.

Overall the diverse range of topics associated with PTW accident characteristics can be divided up into three broad categories; the effect of experience, the effect of speed and PTW performance and the risk of hitting other vulnerable road users. An overall outline of the effects measured is shown in the following table.

Table 1: Sampling frames, study design and additional information

Author, Year, Country	**Sample, method/design and analysis**		**Reference group**	**Additional information on analysis**
B, Mullin et al, 2000, New Zealand	Crash data, Observational, case-control, Odds Ratio between control (survey) and case (collision) group – sample of 1,696 PTW users.	PTW users who were admitted to hospital	PTW users who were recruited through road side surveys	-
G, Cunningham et al, 2012, Australia	Crash data, Observational. Absolute difference between injury outcomes – sample of 205 PTW users.	PTW users who were admitted to hospital with poor injury outcomes	PTW users who were admitted to hospital with good injury outcomes	Only PTW users who provided travel speed included in analysis (n=113)
J, Langley et al, 1999, New Zealand	Crash data, Observational, case-control, Odds Ratio between control (survey) and case (collision) group - Sample of 1,696 PTW users.	PTW users who were admitted to hospital	PTW users who were admitted to hospital	Only PTW users recruited (by hospital admission or survey) between 06:00 and 00:00.
N, Clabaux et al, 2014, France	Crash data, Observational, Odds Ratio between PTW group (n=11) and 4 wheeled group (n=19).	PTW involved in collisions with pedestrians	4 wheeled vehicles involved in collisions with pedestrians	Hourly vehicle traffic data used to calculate rates.

2.2 DESCRIPTION OF AVAILABLE STUDIES

Studies typically investigate the subject of PTW accident characteristics through real world collision data, study design is observational with a smaller number applying a case-controlled approach by recruiting PTW users from road side surveys. Injury severity results are generally provided as an Odds Ratio (OR) through simple bivariate or multivariate associations. Where made, adjustments for associations or variables of interest are through logistic regression analysis. Typically there are a wide range of confounding factors associated with PTW collisions and these are generally well controlled for in the study sample.

All studies focussed on the vehicle types of PTW however this can have different definitions. In three of the four studies this was broadly along the lines of the International Classification of Diseases definition as described by the world health organisation. This definition describes a two wheeled vehicle having one or two riding saddles and sometimes having a third wheel for support of a sidecar. This includes motorised bicycles (mopeds) and scooters. In one study this definition was expanded to include trike and quad bike crash victims in the sample, this only included traditional trikes and quad bikes i.e. those fitting the silhouette of a 3 or 4 wheeled motorcycle (L6e-A class) and not the emergent heavy quadricycle classification (L7e-A/B/C classes).

Table 2: Study results: overview of characteristics and effects for coded studies

Author, Year, Country	Exposure variable	Outcome variable / Outcome type	Effects		Main outcome -description
B, Mullin et al, 2000, New Zealand	Motorcycle familiarity	Injury or fatality through PTW crash	↘	OR=0.52, CL=95%, CI=0.35-0.79	Significant decrease in risk of crash if PTW rider has ≥10,000km previous riding on particular PTW.
	Rider age	Injury or fatality through PTW crash	↘	OR=0.46, CL=95%, CI=0.26-0.81	Significant decrease in risk of crash if PTW rider is 25 years of age or older.
G, Cunningham et al, 2012, Australia	PTW travel speed the same as posted limit	Injury crash	↗	ISS difference = +3.39 (Absolute difference between mean reference ISS score of 7.75 for below speed limit crashes)	Significant increase in mean ISS score for PTW riders travelling at posted speed limit compared to below posted speed limit
	PTW travel speed above posted limit	Injury crash	↗	ISS difference = +4.21 (Absolute difference between mean reference ISS score of 7.75 for below speed limit crashes)	Significant increase in mean ISS score for PTW riders travelling above posted speed limit compared to below posted speed limit
J, Langley et al, 1999, New Zealand	PTW engine size - 250cc	Injury or fatality through PTW crash	-	OR=1.74, CL=95%, CI=1.13-2.69	Non-significant increase in crash risk compared to <250cc engine size.
	PTW engine size - 251cc to 499cc	Injury or fatality through PTW crash	-	OR=1.06, CL=95%, CI=0.64-1.76	Non-significant increase in crash risk compared to <250cc engine size.
	PTW engine size - 500cc to 749cc	Injury or fatality through PTW crash	-	OR=1.72, CL=95%, CI=1.05-2.81	Non-significant increase in crash risk compared to <250cc engine size.
	PTW engine size - 750cc	Injury or fatality through PTW crash	-	OR=1.86, CL=95%, CI=1.12-3.07	Non-significant increase in crash risk compared to <250cc engine size.
	PTW engine size - 751cc to 999cc	Injury or fatality through PTW crash	-	OR=1.78, CL=95%, CI=0.97-3.28	Non-significant increase in crash risk compared to <250cc engine size.
	PTW engine size - 1000cc+	Injury or fatality through PTW crash	-	OR=1.56, CL=95%, CI=0.94-2.58	Non-significant increase in crash risk compared to <250cc engine size.
Clabaux et al, 2014, France	Using PTW in urban area	Hitting a pedestrian	↗	OR=3.06, CL=95%, CI=2.26-4.14	Significant increase in risk of hitting a pedestrian compared to 4 wheeled vehicle.

↗ = Significantly greater risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).
↘ = Significantly less risk of accident/injury on the road type highlighted in 'outcome variable/outcome type' column compared with the baseline road type (highlighted in 'Main outcome-description column).
- = Differences in accident rates/injury risk may have been found, but not statistically significant.

2.3 CONCLUSION

Results from the combination of PTW accident characteristic studies indicate that there are significant and varied risks for riders of powered two wheeled vehicles. The results show that for most cases the injury outcome for PTW riders is made worse by the risks identified to that expected by a four wheel user in the same circumstances. Summarising the results indicate that a young rider riding an unfamiliar PTW with a large engine at or above the posted speed limit and in the presence of pedestrians will present a much higher risk of injury or mortality than an older experienced rider on a familiar PTW with a small engine below the speed limit and away from pedestrians.

3 Supporting Document

3.1 METHODOLOGY

Literature Search strategy

Literature search was conducted in May 2016. It was carried out in two databases with broadly similar search strategies. Following databases were browsed through during the literature search: 'Scopus' and 'TRID'. The same search was conducted for both PTW and pedestrian road user types so the following information is shown for both; final numbers are only shown for the specific road user relevant for this synopsis. Detailed search terms, as well as their linkage with logical operators and combined queries are shown in the following tables:

Database: Scopus **Search Date**: 04/05/2016

Search no.	Search terms / operators	Hits
#1	"EuroNCAP" OR "safety rating" OR "electric vehicles" OR "special vehicle" OR "ATV" OR "all-terrain vehicle*" OR "quad bike*" OR "regulation*" OR "functional safety"	1,708,344
#2	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	643,086
#3	"risk*" OR "severity" OR "frequency"	5,889,383
#4	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mota*"	12,623
#5	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	233,162
#1 AND #2 AND #3 AND #4	All years	81
#1 AND #2 AND #3 AND #5	All years	110

After excluding the papers before 1990, we conclude in the following:

General-PTW : 73
***General -Pedestrians**: 106 – Not included in final PTW search*

Database: TRID **Search Date**: 11/05/2016

Search no.	Search terms / operators	Hits
#1	"EuroNCAP" OR "safety rating" OR "electric vehicles" OR "special vehicle"	7033
#2	"ATV" OR "all-terrain vehicle*" OR "quad bike*"	675

#3	"regulation*" OR "functional safety"	15000
#1 OR #2 OR #3 (referred to as #4)		22463
#5	"road safety" OR "crash*" OR "traffic accident*" OR "collision*" OR "incident*" OR "accident rate" OR "Road Casualties" OR "Road Fatalities"	15000
#6	"risk*" OR "severity" OR "frequency"	15000
#7	"PTW" OR "Powered two wheeler*" OR "motorcycle*" OR "motorbike*" OR "scooter*" OR "moped*" OR "mota*"	9919
#8	"Pedestrian*" OR "walk*" OR "Pedestrian-vehicle crash"	15000
#4 AND #5 AND #6 AND #7	All years	22
#4 AND #5 AND #6 AND #8	All years	52

After excluding the papers before 1990, we conclude in the following:
General-PTW : 22
General-Pedestrians*: 52 – Not included in final PTW search*

PTW papers accounted for 87; removed from this search to show results only for Design-General search:

	Design-General
Total number of studies to screen title/ abstract	95
-De-duplication	3
-Not relevant studies excluded	12
-Studies with no risk estimates excluded	30
Studies not clearly relevant to the topic (full-text screening later)	20
Remaining studies	30
Studies to obtain full-texts	4

Prioritizing Step A (most recent studies)
Prioritizing Step B (Journals over conferences and reports)

No meta-analyses were found

Initial screening involving de-duplication, removal of non-relevant studies and other studies showing no clear risk estimates resulted in 50 remaining studies. These were screened more thoroughly using abstracts to determine whether they could be used for this synopsis. In total a further 20 were removed at this stage for similar reasons identified above, for example, non-relevance or lack of risk estimates but also due to foreign language text or lack of statistical robustness. In total full text were available for 30 studies of which four were fully coded and are the focus of this synopsis.

3.2 REFERENCES

1) Mullin, B., Jackson, R., Langley, J., & Norton, R. (2000). Increasing age and experience: Are both protective against motorcycle injury? A case-control study. Injury Prevention, 6(1), 32–35.

2) Cunningham, G., Chenik, D., & Zellweger, R. (2012). Factors influencing motorcycle crash victim outcomes: A prospective study. ANZ Journal of Surgery, 82(7-8), 551–554.

3) Langley, J., Mullin, B., Jackson, R., & Norton, R. (2000). Motorcycle engine size and risk of moderate to fatal injury from a motorcycle crash. Accident Analysis and Prevention, 32(5), 659–663.

4) Clabaux, N., Fournier, J.-Y.,Michel, J.-E. (2014). Powered Two-Wheeler Drivers' Risk of Hitting a Pedestrian in Towns. Journal of Safety Research, 51, pp 1–5.

Passenger Cars - Risk of injury in frontal impacts: driver, front passenger, and rear passengers

1 Summary

Leopold, F., LAB, France, September 2016

1.1 COLOUR CODE: RED

The bibliographic review on frontal impacts suggests that this type of impact can be given the colour code **red** (risky). This colour code comes from the fact that frontal impacts are not the most dangerous types of impacts, but are by far the most common types of impacts thus resulting in big numbers of severe and fatal injuries.

1.2 KEYWORDS

Passenger cars; frontal impact; injury mechanism; driver; front passenger; rear passengers; seatbelt; airbag; intrusion; interior contact points;

1.3 ABSTRACT

Frontal impacts are those occurring to the front-end of a vehicle and generally defined by the principal direction of force (PDOF) between 11 and 1 o'clock or by the principal area of damage as being the front of the vehicle. Many vehicle factors can influence the outcome of a frontal impact just like the position of the occupant in the vehicle (driver, front passenger, rear left passenger ...), vehicle safety equipment (seatbelts, airbags...), and aggressiveness or protection capacity of different vehicle interior components .

This document is a review of frontal impact risk factors. A systematic literature search has been conducted and relevant studies have been analysed. These studies were very diverse in their nature (different samples, different exposures and outcomes) and a bibliographic review has been achieved in order to outline important conclusions. Results show that frontal impacts are more risky than rear impacts but less risky than side impacts. In frontal impacts, front passengers and rear passengers have almost the same chance of getting fatally injured. Unbelted rear passengers may increase the risks of driver fatality, especially in severe crashes. Airbag deployment reduces the risk of injury especially when combined with seatbelt use. Seatbelts were found to reduce the risks of severe brain injury for full frontal and offset frontal impacts. Second generation, depowered airbags increase injury risk for the thoracic region and decrease injury risk for the upper extremity region when compared with first generation airbags.

1.4 BACKGROUND

Prevalence

Frontal impacts are the type of impact that causes the greatest amount of fatalities between drivers, front passengers, and rear passengers. The number of killed drivers in frontal impacts is the biggest when compared to the numbers of other occupants that were killed. This comes from the fact that vehicle occupancy rate is very low meaning that most of the times drivers are alone in their vehicles. Consequently, many studies focused on drivers in frontal impacts however other studies were found that dealt with front and rear passengers.

Definitions of risk factor

In frontal impacts, there are many risk factors that may influence the outcome on vehicle occupants. The factors analysed in the selected studies are the following:

- **The position of the occupant in the vehicle**. Protection to drivers or front passengers or rear passengers may not be the same when dealing with a frontal mpact.
- **Intrusion to the occupant's compartement.**
- **Agressiveness of vehicle interior design**. Many contact points between occupants and vehicle interior may be more aggressive than others.
- **Different types of frontal impacts** like impacts distributed on the front of the vehicle or impacts with offset. Note that we don't go into details of small overlap frontal crashes because this theme will be detailed in another synopsis.
- **Belt use and airbag deployment in frontal impacts.**
- **Risks and advantages of new generation (depowered) airbags.**

Measures of effect

The effect frontal impacts have on road safety has been evaluated as risks and expressed through risk ratios or odds ratios for injuries of different severities and for different body regions. Different scales of injury severity have been used: the Abbreviated Injury Scale (AIS), the Injury Severity Score (ISS), and the Glasgow Coma Scale (GCS) for brain injuries. Sometimes the scale is only fatal injury or no fatal injury. In general, fatal injury could be defined as death occurring in the thirty days following the accident but this definition could change, depending on the study.

Study methods

All studies selected for this synopsis are observational epidemiological studies. Most studies established a threshold for injury severity and separated the population into two parts: the ones whose injury severity is below the threshold and the ones with injury severity above the defined threshold. Exposure effects were then studied and compared in both groups. Most studies used logistic regression or Cox regression in order to deduce odds ratios or relative risks.

1.5 NOTES ON ANALYSIS METHODS

The selected studies are relatively recent (2008-2015) and mostly deal with analysis performed on US data. Only two studies used European data.

Transferability to other countries can be considered, but one should be very careful. Vehicle model year and the specific fleet of each country should be taken into account. Occupants specifics should also be taken into account as age, height and weight distribution of vehicle users may change from one country to another. For example, occupant vulnerability and accident implication rate highly depend on age.

The analysis methods are very robust and for each study confounding factors have been taken into account.

2 Scientific Overview

2.1 LITERATURE REVIEW

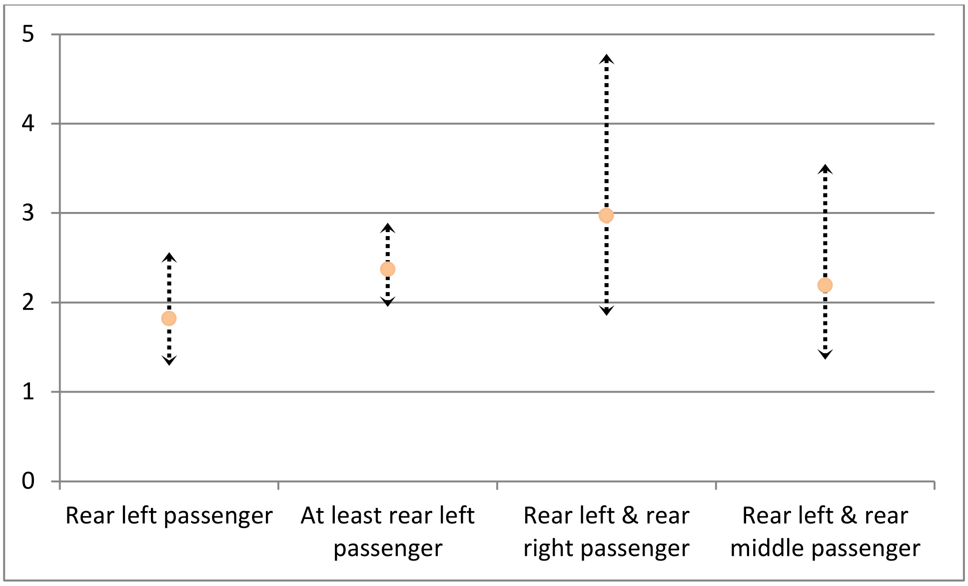
Frontal impacts are found to be the type of impact that causes the biggest amount of fatalities. (Martin, Lardy, and Compigne 2010) showed that frontal impacts in France during the period 1996-2006 accounted for 2213 fatalities while both side impacts and rear impacts accounted for 1540 fatalities. These numbers show the size of the problem but it does not indicate that passengers are more at risk in frontal impacts. Indeed, this same study shows that the proportion of fatalities, which can be directly linked to the risk of fatality, is more important in side impacts than in frontal impacts but less important in rear impacts than in frontal impacts. Other studies (Dupont et al. 2010; Kononen, Flannagan, and Wang 2011) showed respectively that in frontal crashes, occupants have a greater chance of survival than in all other types of crashes combined (OR=2.66) and more risk of getting seriously injured (ISS 15+) in a frontal impact than in a rear impact (OR=2.97). Although the databases used are not the same (French, European, and U.S. databases), neither do the methods of analysis, the latter three studies seem to converge to a same simple deduction: frontal impacts involve more risk for occupants than rear impacts but less risk than side impacts.

However, this deduction may change if we take into account the occupant's position inside the car before impact. For example, for rear occupants, the risk of being fatally injured in rear impacts is higher than in frontal impacts (Martin, Lardy, and Compigne 2010). In frontal impacts, the risk of fatal injury is slightly higher for drivers than for front passengers and slightly higher for front passengers than for rear passengers (Martin, Lardy, and Compigne 2010). The latter affirmation can be confirmed in another study (Durbin et al. 2015) that demonstrated that rear passengers have slightly less risk of being fatally injured as compared to front passengers (OR=0.96).

In frontal impacts, risks for occupants can also vary, depending on the occupation status of other occupants' positions in the cars. (Bose et al. 2013) studied the effect of the presence of unbelted rear passengers on driver fatalities. **Figure 2. 1** shows the odds ratios and 95% confidence interval (CI) for driver fatality with the presence of unbelted rear seat passengers compared to the presence of belted rear passengers. When only the rear left passenger is unbelted, the driver odds of getting a fatal injury are 82% higher compared to when this passenger is belted. When additional unbelted rear passengers happen to be present at the same time with an unbelted rear left passenger, the odds ratios are even higher. For example, the odds of driver fatality with the presence of at least an unbelted rear left passenger are 137% higher than when the rear passengers are belted. The odds of driver fatality with the presence of an unbelted rear left and rear middle passengers are 119% higher than when these passengers are belted and with unbelted rear left and rear right passengers, the odds are even 3 times higher than when they are belted.

Other factors like gender, ejection, vehicle type and airbag deployment have been investigated in (Bose et al. 2013) at the same time with the presence of at least an unbelted rear left passenger. The results show that females are more at risk compared to males, when rear left passengers are unbelted. They also show that ejection multiplies by 30 the odds of driver fatality when rear left passengers are unbelted. As to vehicle type, it has been shown that SUVs and light trucks are more protective for drivers than cars when unbelted rear left passengers are present. Minivans have almost the same protection level as cars but this latter result is statistically not significant.

Figure 2. 1 Odds ratios and 95% CI for driver fatal injury with the presence of unbelted rear passengers vs the presence of belted rear passengers. All are statistically relevant. Data issued from (Bose et al. 2013).



The effect of airbag deployement was also studied. (Bose et al. 2013) showed that the odds of driver fatality when airbag deployed are 2.65 times higher than when airbag did not deploy, when at least an unbelted rear left passenger is present. This result is biased and cannot be interpreted as if airbag deployement is dangerous for drivers. Indeed, crash severity is a confounding factor as airbags only deploy at a ceratin delta-V threshold. So this result also compares severe to mild impacts. In order to eliminate this bias, (Bose et al. 2013) divided their sample into four populations A, B, C, and D as shown in **Table 2. 1**. On one hand, odds of driver fatality when airbag deployed with the presence of at least an unbelted rear left passenger (case C) was compared to the odds of driver fatality when airbag deployed with the presence of belted rear left passengers (case A) and on the other hand, odds of driver fatality when airbag did not deploy with the presence of at least an unbelted rear left passenger (case D) was compared to the odds of driver fatality when airbag did not deploy with the presence of belted rear left passengers (case B).

Table 2. 1 The four populations A, B, C & D used in (Bose et al. 2013) in order to study the effect of airbag deployement.

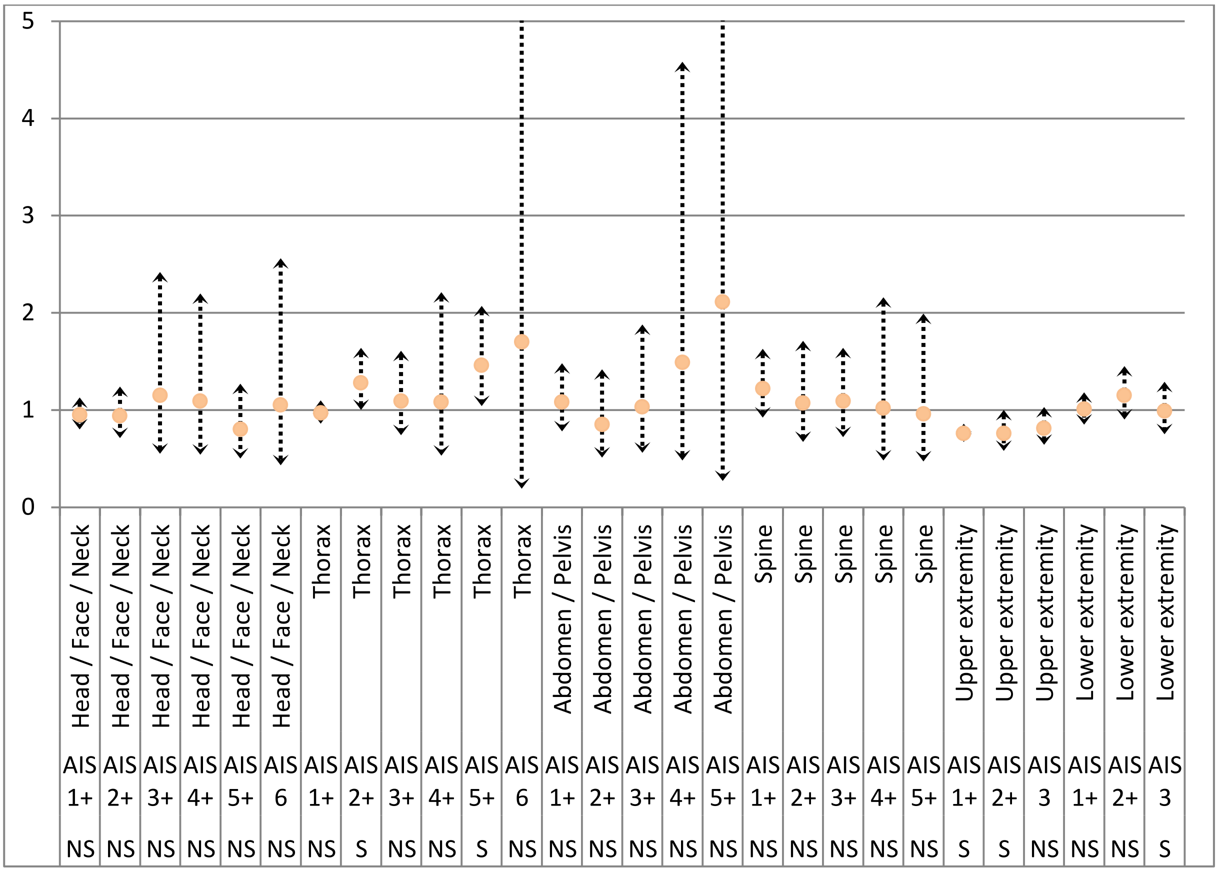
	A	**B**	**C**	**D**
Rear passenger belt status	Belted	Belted	Unbelted	Unbelted
Frontal airbag deployement	Deployed	Not deployed	Deployed	Not deployed

Equation (1) shows that odds ratios of driver fatality when airbag has deployed is lower than odds ratios of driver fatality when airbag has not deployed.

$$\frac{Odds\ of\ C}{Odds\ of\ A} = 1.99 < \frac{Odds\ of\ D}{Odds\ of\ B} = 4.49 \quad (1)$$

Another study (MacLennan et al. 2008) illustrated airbag effect in frontal impacts. It compared the protectiveness of first and second generation airbags for different body regions. Second generation airbags were defined as airbags manufactured after 1997 that were depowered to decrease injury risks for children and small adults. (MacLennan et al. 2008) suspected that depowered airbags may have less protection capacity. Results of this study are illustrated in **Figure 2. 2**.

Figure 2. 2 Relative risks and their 95% CI of injuries of different severities and different localisations for front occupants in vehicles equipped with second generation airbags vs occupants in vehicles equipped with first generation airbags. Data issued from (MacLennan et al. 2008). S: statistically significant & NS: statistically not significant.



Statistically significant results show that risks of thorax AIS 2+ and AIS 5+ injuries are respectively 28% and 46% higher in vehicles equipped with second generation airbags. Significantly higher risks are also observed for abdomen/pelvis AIS 4+ and AIS 5+ injuries but without being statistically significant. On the other hand, second generation airbags were found more protective for upper extremity AIS 1+ (RR = 0.76), AIS 2+ (RR = 0.76), and AIS 3 (RR = 0.81) injuries with statistically significant results on AIS 1+ and AIS 2+. All risk ratios presented in **Figure 2. 2** were adjusted for maximum intrusion, seatbelt use, seat track position, driver/passenger status, and vehicle curb weight.

The outcome of a frontal impact may depend on the impact point and impact distribution on the exterior of the vehicle. One study (Coimbra et al. 2008) investigated how damage distribution across the frontal plane can affect brain injury severity. Frontal impacts have been sorted into three categories: distributed (damage area greater than 66% of the vehicle's frontal plane), offset (35% to 65% of damage to vehicle's frontal plane), and corner (only the corner of vehicle's front is damaged). Two different scales of brain injury severity have been used: the Glasgow Coma Scale (GCS) and the Abbreviated Injury Scale (AIS). Brain injury was considered severe if GCS < 9 or if AIS > 2.

The effect of belt use on brain injury severity in different types of frontal impacts is illustrated in **Figure 2. 3** and **Figure 2. 4**. In distributed and offset frontal impacts, seatbelt use was protective againt brain GCS <9 and AIS 3+ injuries, while in corner frontal impacts the risk of severe brain injury was increased by the use of seatbelt. The latter affirmation cannot be taken into account because it is not statistically significant.

For all types of frontal impacts combined, it is found that seatbelt use decreases the odds of severe brain injuries by approximately 80% (OR = 0.59 for GCS < 9 & 0.61 for AIS 3+ brain injuries).

Figure 2. 3 Odds ratios and 95% CI for severe brain injury (GCS < 9) for belted vs unbelted drivers in different types of frontal impacts. S: Statistically significant. NS: statistically not significant. Data issued from (Coimbra et al. 2008).

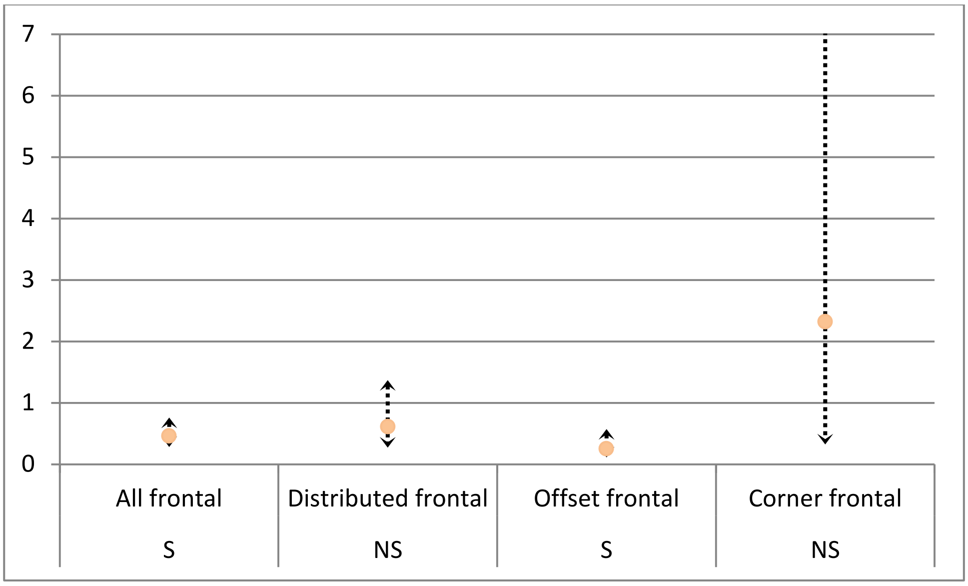
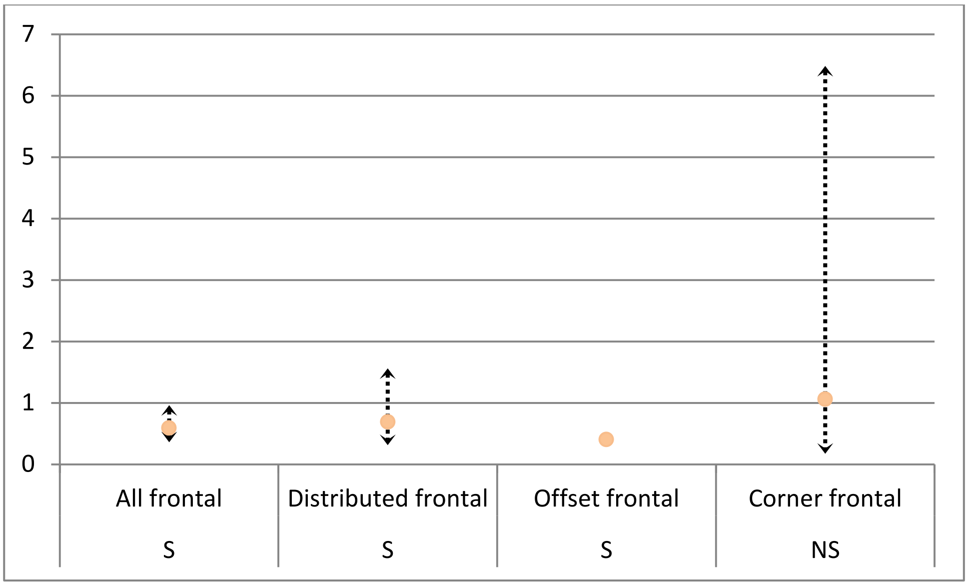


Figure 2. 4 Odds ratios and 95% CI for severe brain injury (AIS 3+) for belted vs unbelted drivers in different types of frontal impacts. S: Statistically significant. NS: statistically not significant. Data issued from (Coimbra et al. 2008).



The effect of intrusion on brain injury severity in different types of frontal impacts is illustrated in **Figure 2. 5** and **Figure 2. 6**. Intrusion to the occupant's seat position was divided into two categories: intrusion < 15 cm and intrusion > 15 cm. In distributed frontal impacts, intrusion was four times more likely to result in severe GCS < 9 brain injury (OR = 4.35) and three times more likely to result in severe AIS 3+ brain injury (OR = 3.33) while in offset frontal impacts, intrusion was two and a half times more likely to result in severe AIS 3+ brain injury (OR = 2.52). In corner frontal impacts, the risk of severe brain injury was largely decreased when intrusion was greater than 15 cm but this affirmation cannot be taken into account because it is not statistically significant.

For all types of frontal impacts combined, it is found that intrusion increases the odds of severe brain injuries.

Figure 2. 5 Odds ratios and 95% CI for driver severe brain injury (GCS < 9) for intrusion > 15 cm vs intrusion < 15 cm in different types of frontal impacts. S: Statistically significant. NS: statistically not significant. Data issued from (Coimbra et al. 2008).

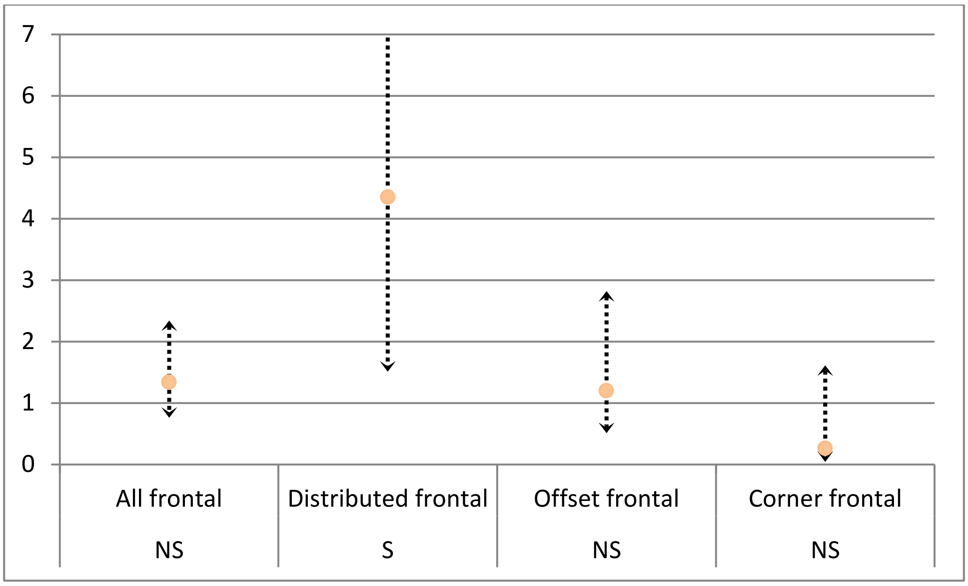
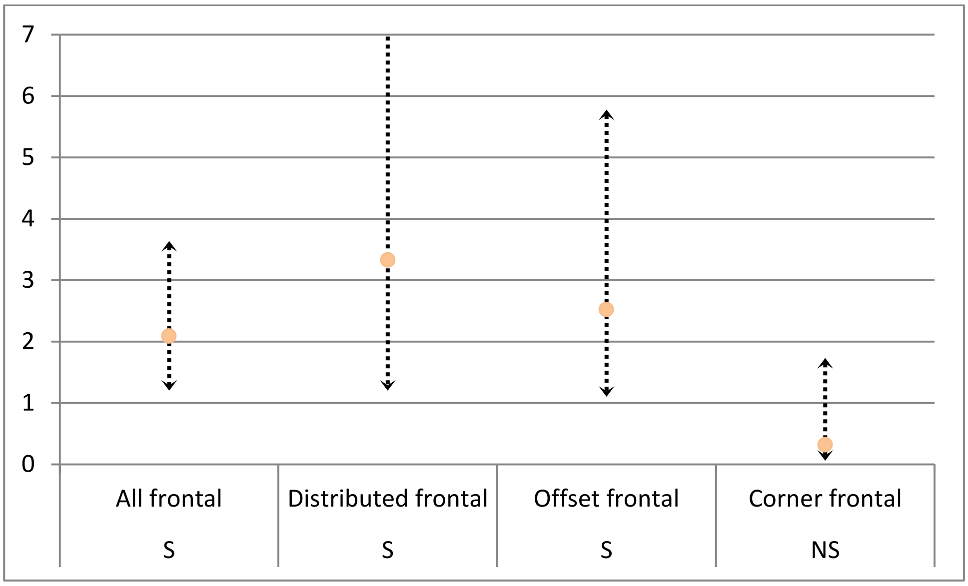
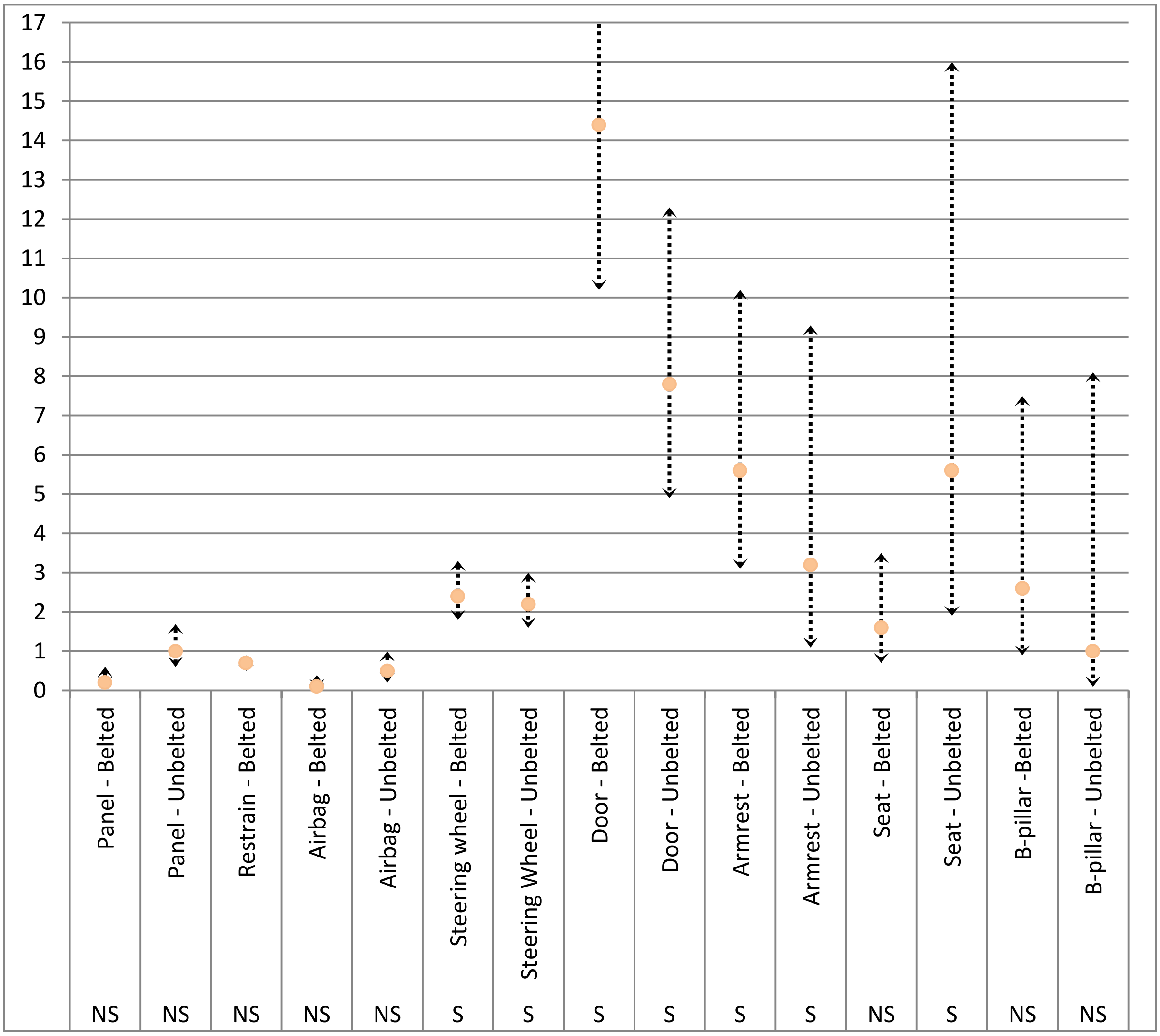


Figure 2. 6 Odds ratios and 95% CI for driver severe brain injury (AIS 3+) for intrusion > 15 cm vs intrusion < 15 cm in different types of frontal impacts. S: Statistically significant. NS: statistically not significant. Data issued from (Coimbra et al. 2008).



Vehicle interior design and specific occupant contact points also have an influence on the outcome of an impact in terms of occupant injury. (Nirula and Pintar 2008) studied the risk associated to severe AIS 3+ chest injury for different driver contact points in vehicle interior. The study was carried out for different impacts direction (frontal, side and rear) but **Figure 2. 7** illustrates the results for frontal impacts only. The results demonstrate that severe thoracic injury risk is worsened with steering wheel, door, armrest and seat contact. Interestingly, the risk of chest injury was higher among restrained drivers making contact with the steering wheel, door, armrest or B-pillar. A possible theory is that the restraint system increases the amount of energy dissipated from the door, armrest or seat to the thoracic cavity by keeping the driver fixed in the seated position during the impact. Although results are not statistically significant,, contact with the front panel seems to be protective especially if driver was restrained. Indeed, belted drivers have 5 times less chances of getting AIS 3+ chest injuries if they contact the front panel than going to contact with any other point in the vehicle interior. Results show also that belted drivers have 60% less chance of getting severe chest injuries (contact with the restraining system OR = 0.7). Airbag seems to be efficient too, especially if drivers are belted (OR = 0.1). These results were adjusted for occupant age and weight and delta-V of the crash.

Figure 2. 7 AIS 3+ chest injury odds ratios and 95% CI for different contact points in vehicle's interior in frontal impacts for belted and unbelted drivers. Data issued from (Nirula and Pintar 2008). S: statistically significant & NS: statistically not significant.



3 Supporting Document

3.1 METHODOLOGY

Literature search strategy

Two databases have been searched: ***ScienceDirect*** and ***Scopus***. In the latter case, the search was limited to articles title, abstract, and keywords fields because the number of hits it generated was relatively high. In the case of *ScienceDirect*, the search was widened in order to include all fields because the number of hits was relatively low when the search included only title, abstract, and keywords. Other search and selection criteria were used and were the same for both databases:

- Year of publication: 1990 to present
- Document type: all
- Source type: journals and conference papers
- Subject area : all sciences
- Language: English
- Search terms: car AND crashworthiness AND ("frontal impact" OR "frontal crash" OR "frontal collision") AND ("risk of injury" OR "risk to be injured" OR "injury risk" OR "compatibility")

The number of hits was respectively 113 and 44 using *ScienceDirect* and *Scopus*. This gives a total number of 152 studies to screen, taking into account that 5 studies were found in both databases (duplicates). **Table 3.1** gives the numbers for the screening process. At the end of this process, 7 studies were selected as eligible for coding. We then added one study that we thought interesting and that was not found in the systematic search stated above.

Table 3.1 Screening process.

Screening	Number of studies left
All studies to screen	152
Abstract screening	59
Availability of full text	57
Quantitative evaluation of risks (relative risk, odds ratio, ...)	7

3.2 ANALYSIS OF STUDY DESIGNS AND METHODS

The selected studies are very heterogeneous in sample size and sample selection. They also investigated different exposures and outcomes. **Table 3.2** gives a quick summary of studies designs, methods, outcomes, and exposures. Only exposures deeling with frontal impacts have been kept for analysis in this document.

Table 3.2 Quick summary of the studies designs.

Author(s), Year, Country	**Sample & study design**	**Method of analysis**	**Outcome(s)**	**Exposure(s)**
(Durbin et al. 2015) USA	FARS & NASS-CDS 2007-2012 data; Vehicle model years ≥ 2000; Outcome → Exposure;	Logistic regression → Odds Ratio (OR) → Relative Risk (RR);	Cases: fatal injury in rear seats. Controls: no fatal injury in rear seats	Being a rear passenger vs being a front passenger
(Bose et al. 2013) USA	FARS 2001-2009 data; Vehicle model years > 1998; Outcome → Exposure;	Logistic regression → OR	Cases: fatal injury for driver Controls: no fatal injury for driver	Unbelted vs belted rear left passenger
(Kononen, Flannagan, and Wang 2011) USA	NASS-CDS 1999-2008 data; Vehicle model years ≥ 2000; Outcome → Exposure	Logistic regression → OR	Cases: ISS 15+ injury Controls : no ISS 15+ injury	Frontal impact vs rear impact
(Dupont et al. 2010) Europe	European Fatal Accident Investigation database; Outcome → Exposure	Logistic regression → OR	Cases: occupant survived Controls: occupant did not survive	Frontal impact vs other impacts
(Martin, Lardy, and Compigne 2010) France	French police data 1996-2006; Outcome → Exposure	Absolute proportion	Proportion of fatalities	Driver, front passengers, rear passengers
(Coimbra et al. 2008) USA	CIREN 1997-2006 data; Vehicle model years: 1987-2006; Outcome → Exposure	Logistic regression → OR	Cases: severe brain injury Controls: no severe brain injury	- Belted vs unbelted in different types of frontal impacts - Frontal intrusion >15 cm vs < 15 cm in different types of frontal impacts - Driver vs passenger in different types of frontal impacts - Airbag deployed vs airbag not deployed in different types of frontal impacts
(MacLennan et al. 2008) USA	NASS-CDS 1995-2004 data; Vehicle model years: 1987-2005 Exposure → Outcome	Cox regression → RR	- Head-face-neck injuries - Thorax injuries - Abdomen / pelvis injuries - Spine injuries - Upper extremity injuries - Lower extremity injuries - Death	Test group: second generation airbag Reference group: first generation airbag
(Nirula and Pintar 2008)	NASS-CDS 1993-2001 data & CIREN 1996-	Logistic regression → OR	Cases: severe chest injury	- Driver contact with different points of

USA	2004 data; Outcome → Exposure		Controls: no severe chest injury	vehicle interior vs no contact with these points

The selected studies are relatively recent (2008-2015) and mostly deal with analysis performed on FARS (Fatality Analysis Reporting System), NASS-CDS (National Automotive Sampling System – Crashworthiness Data System) and CIREN (Crash Injury Research Engineering Network) data. Two studies used European data (European Fatal Accident Investigation database and French police data). Most studies (7 out of 8) began with the outcome counts (for example fatal injury in frontal impacts) and studied the effect of a certain exposure on that outcome (for example the fact of being a rear seat passenger). Six of these "outcome to exposure" studies used the logistic regression method to deduce odds ratios which means the odds of an outcome to happen given a certain exposure versus the odds of an outcome to happen without this same exposure. When the outcome is uncommon, odds ratios can be used as relative risks as in (Durbin et al. 2015). Another study (Martin, Lardy, and Compigne 2010) used proportions in order to evaluate fatality risks for drivers, front passengers, and rear passengers in frontal, near-side, far-side, and rear impacts. Unlike the studies mentioned above (MacLennan et al. 2008) began their study by selecting two groups of exposures (a test group and a reference group) and used the Cox regression in order to deduce the relative risk of an injury pattern inside the test group versus the same injury pattern inside the reference group.

3.3 DETAILED SUMMARY OF RESULTS

Six of the selected studies use statistical models in order to deduce relative risks (or rates ratios RR) and odds ratios (OR). **Table 3.3** summarizes the results of five of these studies. Only (MacLennan et al. 2008) results are not mentioned in this table but are illustrated in **Figure 2.7**.

Table 3.3 Summary of the results with relative risks (RR), odds ratios (OR) and their 95% confidence interval (CI).

Author	Risk factor	Outcome	Effects for road safety	Interpretation of results
(Durbin et al. 2015)	Rear seat vs front passenger seat	Fatal injury	RR = 0.96 95% CI: 0.75-1.23	Front passengers and rear passengers have almost the same risk of getting fatally injured in a frontal impact. No info on the significance of this result. No p value was given.
(Bose et al. 2013)	Unbelted vs belted rear left passenger	Fatal injury for driver	OR = 1.82 95% CI: 1.29-2.56 $p < 0.05$	Drivers are more likely to get a fatal injury when the rear left passenger is unbelted. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & possibly other unbelted rear passengers vs belted rear passengers	Fatal injury for driver	OR = 2.37 95% CI: 1.95-2.89 $p < 0.05$	Drivers are more likely to get fatal injury when rear left passenger and other rear passengers are unbelted. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & unbelted	Fatal injury for driver	OR = 2.97 95% CI: 1.85-4.78	Drivers are more likely to get fatal injury when rear left

	rear right passenger vs belted rear passengers		p < 0.05	passenger and rear right passenger are unbelted. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & unbelted rear middle passenger vs belted rear passengers	Fatal injury for driver	OR = 2.19 95% CI: 1.36-3.55 p < 0.05	Drivers are more likely to get fatal injury when rear left passenger and rear middle passenger are unbelted. This result is statistically significant
(Bose et al. 2013)	Female driver vs male driver both with the presence of unbelted rear left passenger & possibly other unbelted rear passengers	Fatal injury for driver	OR = 1.23 95% CI: 1.00-1.50 p < 0.05	Female drivers are more at risk of getting fatal injury than male drivers when rear left passenger and other rear passengers are unbelted. This result is statistically significant.
(Bose et al. 2013)	Ejected driver vs not ejected both with the presence of unbelted rear left passenger & possibly other unbelted rear passengers	Fatal injury for driver	OR = 30.96 95% CI: 6.84-140.15 p < 0.05	Ejected drivers are at a much higher risk of getting fatal injury than non ejected drivers when rear left passenger and other rear passengers are unbelted. This result is statistically significant.
(Bose et al. 2013)	SUV vs car both with the presence of unbelted rear left passenger & possibly other unbelted rear passengers	Fatal injury for driver	OR = 0.51 95% CI: 0.39-0.66 p < 0.05	Car drivers are at higher risk of getting fatal injury than SUV drivers when, for both vehicles, rear left passenger and other rear passengers are unbelted. This result is statistically significant.
(Bose et al. 2013)	Minivan vs car both with the presence of unbelted rear left passenger & possibly other unbelted rear passengers	Fatal injury for driver	OR = 0.98 95% CI: 0.70-1.35 p > 0.05	Car drivers have almost the same risk of getting fatal injury than Minivan drivers when, for both vehicles, rear left passenger and other rear passengers are unbelted. This result is statistically not significant.
(Bose et al. 2013)	Light truck vs car both with the presence of unbelted rear left passenger & possibly other unbelted rear passengers	Fatal injury for driver	OR = 0.46 95% CI: 0.33-0.66 p < 0.05	Car drivers are at higher risk of getting fatal injury than light truck drivers when, for both vehicles, rear left passenger and other rear passengers are unbelted. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & possibly other unbelted rear passengers & airbag not deployed vs belted rear	Fatal injury for driver	OR = 4.49 95% CI: 2.98-6.76 P < 0.05	Drivers are more at risk of getting fatal injury when rear left passenger and other rear passengers are unbelted & when airbag did not deploy than when rear passengers

	passengers & airbag not deployed			are belted & airbag not deployed. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & possibly other unbelted rear passengers & airbag deployed vs belted rear passengers & airbag deployed	Fatal injury for driver	OR = 1.99 95% CI: 1.60-2.47 $p < 0.05$	Drivers are more at risk of getting fatal injury when rear left passenger and other rear passengers are unbelted & when airbag deployed than when rear passengers are belted & airbag deployed. This result is statistically significant.
(Bose et al. 2013)	Unbelted rear left passenger & possibly other unbelted rear passengers & airbag deployed vs unbelted & airbag not deployed	Fatal injury for driver	OR = 2.65 95% CI: 2.10-3.34 $p < 0.05$	Drivers are more at risk of getting fatal injury when airbag deployed than when airbag did not deploy, both cases with unbelted rear left passenger & possibly other unbelted rear passenger. This result is statistically significant.
(Kononen, Flannagan, and Wang 2011)	Frontal impact vs rear impact (for medium and severe crashes: delta-V ≥ 15 mph or airbag deployement)	ISS 15+ injury	OR = 2.97 95% CI: 1.14-7.73 $p < 0.05$	In medium or severe frontal crashes, occupants are more at risk of getting an ISS 15+ injury than in medium or severe rear impacts. This result is statistically significant.
(Dupont et al. 2010)	Frontal impact vs other types of impacts combined	Survival of car occupants	OR = 2.66 95% CI: 2.92-3.69 $p < 0.05$	In frontal crashes, occupants have more survival chances than other types of impacts. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in frontal impact vs unbelted	Severe brain injury GCS < 9	OR = 0.46 95% CI: 0.28-0.76 $p < 0.05$	In frontal impacts, belted drivers or front passengers chances of getting a GCS < 9 brain injury are more than half less than unbelted drivers or front passengers. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in frontal impact vs unbelted	Severe brain injury AIS 2+	OR = 0.59 95% CI: 0.36-0.96 $p < 0.05$	In frontal impacts, belted drivers or front passengers have less chances of getting AIS 3+ brain injury than unbelted drivers or front passengers. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in distributed frontal impact vs unbelted	Severe brain injury GCS < 9	OR = 0.61 95% CI: 0.27-1.37 $p > 0.05$	In distributed frontal impacts, belted drivers or front passengers have less chances of getting a GCS < 9 brain injury than unbelted

				drivers or front passengers. This result is statistically not significant.
(Coimbra et al. 2008)	Belted driver or front passenger in distributed frontal impact vs unbelted	Severe brain injury AIS 3+	OR = 0.69 95% CI: 0.31-1.56 $p < 0.05$	In distributed frontal impacts, belted drivers or front passengers have less chances of getting AIS 3+ brain injury than unbelted drivers or front passengers. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in offset frontal impact vs unbelted	Severe brain injury GCS < 9	OR = 0.25 95% CI: 0.11-0.57 $p < 0.05$	In offset frontal impacts, belted drivers or front passengers have 4 times less chances of getting a GCS < 9 brain injury than unbelted drivers or front passengers. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in offset frontal impact vs unbelted	Severe brain injury AIS 3+	OR = 0.4 95% CI: $p < 0.05$	In offset frontal impacts, belted drivers or front passengers have less chances of getting AIS 3+ brain injury than unbelted drivers or front passengers. This result is statistically significant.
(Coimbra et al. 2008)	Belted driver or front passenger in corner frontal impact vs unbelted	Severe brain injury GCS < 9	OR = 2.32 95% CI: 0.32-16.90 $p > 0.05$	In corner frontal impacts, belted drivers or front passengers have more chances of getting a GCS < 9 brain injury than unbelted drivers or front passengers. This result is statistically not significant.
(Coimbra et al. 2008)	Belted driver or front passenger in corner frontal impact vs unbelted	Severe brain injury AIS 3+	OR = 1.06 95% CI: 0.17-6.48 $p > 0.05$	In corner frontal impacts, belted drivers or front passengers have almost the same chances of getting AIS 3+ brain injury than unbelted drivers or front passengers. This result is statistically not significant.
(Coimbra et al. 2008)	Frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury GCS < 9	OR = 1.34 95% CI: 0.76-2.34 $p > 0.05$	In frontal impacts, when frontal intrusion is bigger than 15 cm, chances of driver and front passenger GCS < 9 severe brain injury is higher than when intrusion is smaller than 15 cm. This result is statistically not significant.
(Coimbra et al. 2008)	Frontal impact with frontal intrusion > 15	Severe brain injury AIS 3+	OR = 2.09 95% CI: 1.20-3.64	In frontal impacts, when frontal intrusion is bigger

	cm vs frontal intrusion < 15 cm		$p < 0.05$	than 15 cm, chances of driver and front passenger AIS 3+ severe brain injury is more than twice higher than when intrusion is smaller than 15 cm. This result is statistically significant.
(Coimbra et al. 2008)	Distributed frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury GCS < 9	OR = 4.35 95% CI: 1.51-12.5 $p < 0.05$	In distributed frontal impacts, when frontal intrusion is bigger than 15 cm, chances of driver and front passenger GCS < 9 severe brain injury is more than 4 times higher than when intrusion is smaller than 15 cm. This result is statistically significant.
(Coimbra et al. 2008)	Distributed frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury AIS 3+	OR = 3.33 95% CI: 1.20-9.92 $p < 0.05$	In distributed frontal impacts, when frontal intrusion is bigger than 15 cm, chances of driver and front passenger AIS 3+ severe brain injury is more than 3 times higher than when intrusion is smaller than 15 cm. This result is statistically significant.
(Coimbra et al. 2008)	Offset frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury GCS < 9	OR = 1.20 95% CI: 0.51-2.82 $p > 0.05$	In offset frontal impacts, when frontal intrusion is bigger than 15 cm, chances of driver and front passenger GCS < 9 severe brain injury is higher than when intrusion is smaller than 15 cm. This result is statistically not significant.
(Coimbra et al. 2008)	Offset frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury AIS 3+	OR = 2.52 95% CI: 1.10-5.78 $p < 0.05$	In offset frontal impacts, when frontal intrusion is bigger than 15 cm, chances of driver and front passenger AIS 3+ severe brain injury are more than twice higher than when intrusion is smaller than 15 cm. This result is statistically significant.
(Coimbra et al. 2008)	Corner frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury GCS < 9	OR = 0.26 95% CI: 0.04-1.61 $p > 0.05$	In corner frontal impacts, when frontal intrusion is bigger than 15 cm, driver and front passenger have almost 4 times less chance of getting GCS < 9 brain injury than when intrusion is smaller than 15 cm. This result is statistically not significant.

(Coimbra et al. 2008)	Corner frontal impact with frontal intrusion > 15 cm vs frontal intrusion < 15 cm	Severe brain injury AIS 3+	OR = 0.32 95% CI: 0.06-1.73 $p > 0.05$	In corner frontal impacts, when frontal intrusion is bigger than 15 cm, driver and front passenger have more than 3 times less chance of getting AIS 3+ brain injury than when intrusion is smaller than 15 cm. This result is statistically not significant.
(Nirula and Pintar 2008)	Belted driver contact with the panel vs no contact with the panel	Severe chest injury AIS 3+	OR = 0.2 95% CI: 0.1-0.6 $p > 0.05$	When a belted driver goes to contact with the front panel, he has 5 times less chances of getting AIS 3+ injuries than when there is no contact with the front panel. This result is statistically not significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the panel vs no contact with the panel	Severe chest injury AIS 3+	OR = 1 95% CI: 0.6-1.7 $p > 0.05$	When unbelted driver goes to contact with the front panel, he has almost the same chances of getting AIS 3+ injuries than when there is no contact with the front panel. This result is statistically not significant.
(Nirula and Pintar 2008)	Belted driver vs unbelted	Severe chest injury AIS 3+	OR = 0.7 95% CI: 0.5-0.9 $p > 0.05$	Belted drivers have less chances of getting AIS 3+ injuries than unbelted drivers. This result is statistically not significant.
(Nirula and Pintar 2008)	Belted driver contact with the airbag vs no contact with the airbag	Severe chest injury AIS 3+	OR = 0.1 95% CI: 0.04-0.4 $p > 0.05$	When a belted driver goes to contact with the airbag, he has 10 times less chances of getting AIS 3+ injuries than when there is no contact with the airbag. This result is statistically not significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the airbag vs no contact with the airbag	Severe chest injury AIS 3+	OR = 0.5 95% CI: 0.2-1.0 $p > 0.05$	When unbelted driver goes to contact with the airbag, he has twice less chances of getting AIS 3+ injuries than when there is no contact with the airbag. This result is statistically not significant.
(Nirula and Pintar 2008)	Belted driver contact with the steering wheel vs no contact with the steering wheel	Severe chest injury AIS 3+	OR = 2.4 95% CI: 1.8-3.3 $p < 0.05$	When a belted driver goes to contact with the steering wheel, he has more than twice chances of getting AIS 3+ injuries than when there is no contact with the airbag. This result is statistically significant.

(Nirula and Pintar 2008)	Unbelted driver contact with the steering wheel vs no contact with the steering wheel	Severe chest injury AIS 3+	OR = 2.2 95% CI: 1.6-3.0 $p < 0.05$	When unbelted driver goes to contact with the steering wheel, he has more than twice chances of getting AIS 3+ injuries than when there is no contact with the steering wheel. This result is statistically significant.
(Nirula and Pintar 2008)	Belted driver contact with the door vs no contact with the door	Severe chest injury AIS 3+	OR = 14.4 95% CI: 10.2-20.2 $p < 0.05$	When a belted driver goes to contact with the door, he has 14 times more chances of getting AIS 3+ injuries than when there is no contact with the door. This result is statistically significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the door vs no contact with the door	Severe chest injury AIS 3+	OR = 7.8 95% CI: 4.9-12.3 $p < 0.05$	When an unbelted driver goes to contact with the door, he has 8 times more chances of getting AIS 3+ injuries than when there is no contact with the door. This result is statistically significant.
(Nirula and Pintar 2008)	Belted driver contact with the armrest vs no contact with the armrest	Severe chest injury AIS 3+	OR = 5.6 95% CI: 3.1-10.2 $p < 0.05$	When a belted driver goes to contact with the armrest, he has more than 5 times chances of getting AIS 3+ injuries than when there is no contact with the door. This result is statistically significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the armrest vs no contact with the armrest	Severe chest injury AIS 3+	OR = 3.2 95% CI: 1.1-9.3 $p < 0.05$	When an unbelted driver goes to contact with the armrest, he has 3 times more chances of getting AIS 3+ injuries than when there is no contact with the door. This result is statistically significant.
(Nirula and Pintar 2008)	Belted driver contact with the seat vs no contact with the seat	Severe chest injury AIS 3+	OR = 1.6 95% CI: 0.7-3.5 $p < 0.05$	When a belted driver goes to contact with the seat, he has more chances of getting AIS 3+ injuries than when there is no contact with the seat. This result is statistically not significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the seat vs no contact with the seat	Severe chest injury AIS 3+	OR = 5.6 95% CI: 1.9-16.0 $p < 0.05$	When an unbelted driver goes to contact with the seat, he has more than 5 times chances of getting AIS 3+ injuries than when there is no contact with the seat. This result is statistically significant.

(Nirula and Pintar 2008)	Belted driver contact with the B-pillar vs no contact with the B-pillar	Severe chest injury AIS 3+	OR = 2.6 95% CI: 0.9-7.5 $p > 0.05$	When a belted driver goes to contact with the B-pillar, he has more than twice chances of getting AIS 3+ injuries than when there is no contact with the B-pillar. This result is statistically not significant.
(Nirula and Pintar 2008)	Unbelted driver contact with the B-pillar vs no contact with the B-pillar	Severe chest injury AIS 3+	OR = 1 95% CI: 0.1-8.1 $p > 0.05$	When an unbelted driver goes to contact with the B-pillar, he has almost the same chances of getting AIS 3+ injuries than when there is no contact with the B-pillar. This result is statistically not significant.

3.4 REFERENCES

Bose, Dipan, Carlos Arregui-Dalmases, David Sanchez-Molina, Juan Velazquez-Ameijide, and Jeff Crandall. 2013. "Increased Risk of Driver Fatality due to Unrestrained Rear-Seat Passengers in Severe Frontal Crashes." Article. *Accident Analysis & Prevention* 53: 100–104. doi:http://dx.doi.org/10.1016/j.aap.2012.11.031.

Coimbra, Raul, Carol Conroy, David B Hoyt, Sharon Pacyna, MarSue May, Steve Erwin, Gail Tominaga, Frank Kennedy, Michael Sise, and Tom Velky. 2008. "The Influence of Damage Distribution on Serious Brain Injury in Occupants in Frontal Motor Vehicle Crashes." Article. *Accident Analysis & Prevention* 40 (4): 1569–75. doi:http://dx.doi.org/10.1016/j.aap.2008.04.004.

Dupont, Emmanuelle, Heike Martensen, Eleonora Papadimitriou, and George Yannis. 2010. "Risk and Protection Factors in Fatal Accidents." Article. *Accident Analysis & Prevention* 42 (2): 645–53. doi:http://dx.doi.org/10.1016/j.aap.2009.10.011.

Durbin, Dennis R, Jessica S Jermakian, Michael J Kallan, Anne T McCartt, Kristy B Arbogast, Mark R Zonfrillo, and Rachel K Myers. 2015. "Rear Seat Safety: Variation in Protection by Occupant, Crash and Vehicle Characteristics." Article. *Accident Analysis & Prevention* 80: 185–92. doi:http://dx.doi.org/10.1016/j.aap.2015.04.006.

Kononen, Douglas W, Carol A C Flannagan, and Stewart C Wang. 2011. "Identification and Validation of a Logistic Regression Model for Predicting Serious Injuries Associated with Motor Vehicle Crashes." Article. *Accident Analysis & Prevention* 43 (1): 112–22. doi:http://dx.doi.org/10.1016/j.aap.2010.07.018.

MacLennan, Paul A, William S Ashwander, Russell Griffin, Gerald McGwin Jr., and Loring W Rue III. 2008. "Injury Risks between First- and Second-Generation Airbags in Frontal Motor Vehicle Collisions." Article. *Accident Analysis & Prevention* 40 (4): 1371–74. doi:http://dx.doi.org/10.1016/j.aap.2008.02.008.

Martin, Jean-louis, Audrey Lardy, and Sabine Compigne. 2010. "Specificities of Rear Occupant Protection: Analysis of French Accident Data." In *IRCOBI*, 315–18. Hanover, Germany.

Nirula, R, and F A Pintar. 2008. "Identification of Vehicle Components Associated with Severe Thoracic Injury in Motor Vehicle Crashes: A CIREN and NASS Analysis." Article. *Accident Analysis & Prevention* 40 (1): 137–41. doi:http://dx.doi.org/10.1016/j.aap.2007.04.013.

Light Goods Vehicle - Crashworthiness - Compatibility

1 Summary

Phan, V., September 2016

1.1 COLOUR CODE: RED

Light Goods Vehicle (LGV) compatibility is significantly risky; indeed, mainly due to LGV dimension and weight, most papers conclude that there is a negative effect on road safety; especially for the opponent vehicle. In spite of the improvement done to improve protection and agressivity of LGVs, compatibility is still an issue. The color code is red.

1.2 KEYWORDS

Agressivity, self-protection, LGV, LTV, passenger car, side impact, mass, footprint

1.3 ABSTRACT

Vehicle compatibility is mainly defined and assessed according to the combination of its self-protective capacity and aggressivity when involved in collisions with another vehicles. Self-protection centres on a vehicle's ability toshield its occupants in a collision, whereas aggressivity is measured by the casualty outcomes on occupants of the other vehicles in the collision. As the relative composition of the fleet of vehicles is altered (the number of LGV/LTV is growing in North America and Europe), negative effects on road safety might appear (Fredette et al., 2008). Most studies focus on the compatibility between LGV and passenger cars, as it is the most common accident configuration. The overall conclusion is that the risk of injury at all levels of severity is greater in cars than in LGVs.

1.4 BACKGROUND

What is compatibility?

The compatibility of a vehicle is a combination of its crashworthiness and its aggressivity when involved in crashes with other members of the vehicle fleet. While crashworthiness focuses on the capability of a vehicle to protect its occupants in a collision, aggressivity is measured in terms of the casualty outcome of occupants of the other vehicles involved in the collision. Improvements in crash compatibility may require improvements in crashworthiness coupled with simultaneous reductions in aggressivity.

How does compatibility affect road safety?

Over the last few decades in the USA and Europe theLGV vehicle fleet has increased markedly. LGVs compared with passenger cars differ in usage but also in terms of geometry and mass. It is for these reasons that the difference in mass increases the self-protection and aggressivity of the heavier vehicle, whereas geometric incompatibility (e.g., a passenger car versus a LTV) generally penalizes the lightest, samllest vehicle.

Which safety outcomes are affected by compatibility?

In the literature review, compatibility is studied by comparing the risk of injury inside the LTV and inside the opponent vehicle (mainly a passenger car).

How is the effect of compatibility studied?

There are several ways to study the effect of compatibility as the definition of this risk is a mix of self-protection and partner protection. More than half of the papers use models (e.g. logisitic and probit models) to quantify the probability of injuries inside and outside a vehicle for a LGV-passenger car collision. These papers compare the risk between vehicle types.

The remaining papers compare (ratio) the number of injured road users inside and outside an LGV in the event of a collision.

In addition the LGV body type is also a factor which is studied. Indeed, most of the articles are from the USA where the classification of LGV includes several types of vehicle (light truck, pick-up, vans, minivans…).

1.5 OVERVIEW OF RESULTS

In Germany, in accordance with their road usage, passenger cars are the most frequent counterpart in the event of a collision with an LGV. The frequency of this collision accounts for approximately 50% of LGV collisions. In 30% of the LGV collision cases the vehicle collides with unprotected road users such as pedestrians or cyclists (Dekra et al., 2013).

Irrespective of the method of analysis (ratio, logistic regression), for an LGV-passenger car accident, at all levels of severity, an LGV is more agresive for passenger car road users than a passenger car is for LGV road users. In addition the risk of injury at all levels of severity is greater in cars than in vans.

1.6 NOTES ON ANALYSIS METHODS

As mentioned previously, most studies rely on data from US accident databases. The classification of LTVs made by US researchers includes Light Trucks, Vans, minivan and Pickup trucks and includes vehicles carrying either passengers or goods. The LGV definition in WP6 however is defined as a vehicle used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.

2 Scientific Overview

2.1 LITERATURE REVIEW

Light Goods Vehicle or LGV is mainly a vehicle category term used in Europe. There are a variety of other terms commonly used to describe such vehicles, these inlcude: Light Commercial Vehicles, e.g. Vans, Light Utility Vehicles (LUV) etc.

Unfortunately only a few studies in Europe have focused their analysis on LGV compatibility risk measurement. For this reason the literature review has been extended to include the categories of Light Truck and Vans (a classification used predominantly in North America).

Although it is not possible to define vehicle compatibility absolutely due to the varience between papers all the articles study the same effects as defined by Abdel-Aty, M. (2004):

Compatibility means that vehicles of disparate size provide an equal level of occupant protection in vehicle-to-vehicle collisions. The compatibility of a vehicle is a combination of its collision worthiness (the vehicle's capability of withstanding the effects of a collision) and its aggressivity when involved in collisions with members of the vehicle fleet.

Most of the articles reviewed here study the compatibility (or incompatibility) between LGV and passenger cars. Indeed such vehicles are the most common classes of vehicle in the US and in several countries in Europe. As registrations and sales of LTV vehicle types increase, this type of collision could increase correspondingly.

Seven articles are studies from American or Canadian research institutes. These countries began working on this compatibility problem at the beginning of the 1990's when more than 30% of new registrations were LTVs and passenger car-LTV collisions resulted in more than half of the killed or injured road users; most of these being car occupants.

In the papers analysed here, two mains compatibility factors are studied:

- Incompatibility of vehicle mass: LTVs are heavier, LTVs can carry loads.
- Incompatibility of vehicle geometry: LTVs include different kinds of vehicle category and vehicle design such as compact SUVs, full-size SUVs, minivans, full-size vans, compact pickup trucks, full-size pickup trucks etc.

2.2 DESCRIPTION OF THE AVAILABLE STUDIES

Statistical analysis

DEKRA (2013) has initiated a research project describing the safety of Light Commercial Vehicles. The analyses of this project are based upon data drawn from the official German road traffic accident statistics, the accident database of the German insurers (UDB) and DEKRA as well as those of the German In-Depth Accident Study (GIDAS). It has been revealed that accidents involving Light Commercial Vehicles show a similar pattern to those involving passenger cars; noteworthy differences can be established in connection with accidents involving pedestrians, vehicle reversing and the causes of accidents. The level of passenger protection in the Light Commercial Vehicle is currently not being exploited to the full, however, as the number of those making use of the safety belt is significantly lower than it is with passengers in passenger cars. In connection with partner protection it is to be stated that, in the event of a collision with a passenger car, the energy absorbing vehicle structures are not compatible.

Lenard et al(2004) quantified the agressivity index of LGVs and the relative injury risk (LGV compared to cars), using the British national STATS19 database and accidents from 1994 to 1998. The aggressivity index is the ratio of occupants injured in the passenger car to the total number of injured occupants in the collision. It ranges in value from ozero (low aggressivity) to one(high aggressivity). The relative injury risk is the ratio of occupants injured in the LGV to the number of occupants injured in the passenger car. It ranges in value from zero (low injury risk) to infinity (high injury risk). At all levels of severity, LGV is more agressive for passenger car road users than passenger cars are for LGV road users. And the risk of injury at all levels of severity is greater in cars than in LGVs.

Both previous papers have defined LGV as light goods vehicles, up to 3500 kg gross vehicle mass.

Gabler et al. (2003) used 1997 to 2001 data from the US Fatality Analysis Reporting System (FARS) to describe incompatibility for passenger cars in left side impacts with LTVs (Light Truck and Vans) or another car For every driver who dies in a striking LTV, 43 side struck car drivers are fatally injured when the struck car is of model year 1980-89. By contrast, if the struck car is of model year 1997-2001, for every fatally injured driver of a striking LTV, 17 side-struck car drivers are killed. When the striking vehicle is a car (and the struck vehicle is a car), the results are 1 for 12 and 1 for 7, respectively.

Statistical modelling

Self-protection and/or partner protection

Ossiander et al. (2010) estimated the effect of vehicle incompatibility in collisions between cars and light trucks or vans. That is to say they have estimated the harm imposed and protection offered by LTVs compared to cars, and the joint effect of these on the risk of death. The study has used a case-control design. From each eligible fatal crash, all fatalities were selected as cases, and from each eligible non-fatal crash, one person was selected as a control. They drew cases from the Fatality Analysis Reporting System (FARS) and controls from General Estimates System (GES), both maintained by the National Highway Traffic Safety Administration (NHTSA). Both cases and controls were selected from collisions occurring between 1990 and 2008 in which two passenger vehicles (cars, pickups, SUVs, or vans) and no pedestrian were involved. Both vehicles were model year 1980 or later.

Logistic regression was used to estimate odds ratio of death according to the type of vehicle in which the road user was and the type of vehicle the road user crashed with. They compared the risk of death according to the type of vehicle invovled in the collision. They have considered car, compact SUV, ful-size SUV, Minivan, Full-size van, compact pickup and full-size pickup.

The risk of death is higher in a passenger car than in any kind of LTV (odds ratio from 0.32 for full-size pickup to 0.76 for compact SUV compared to passenger car) when road users are involved in two passenger vehicles collision. And the risk of death is higher when a passenger vehicle is in a collision with any kind of LTV compared to a passenger car (odds ratio from 1.8 for compact pickup to 4.8 for full-size van).

When considering both vehicles in a collision and comparing the road user risk of death in the accident, for all collisions involving at least a LTV, the road user involved in has a higher risk of death comparing to a road user involved in a passenger car to passenger car collision.

Fredette et al. (2008) evaluated the same compatibility indicators as Ossiander et al. using the Canadian National Collision Database (NCDB)to analyse two vehicle collisions.. These collisions exclude those involving motorcycles, bicycles, snowmobiles, or all-terrain vehicles, and those where the type of one or both vehicles involved was missing. It means that the collisions involved only car, pickup truck, minivan, SUV, heavy truck and bus.

The results are similar to the ones found in Ossiander et al. study. Indeed, the risk of death or hospitalization is higher for passenger car road users than for any other vehicle road users (pickup, minivan, SUV, Heavy truck, Bus - odds ratio from 0.23 for bus to 0.90 for SUV compared to passenger car). The risk of death or hospitalization is higher for road user involved in a collision against any kind of vehicle which is not a car (odds ratio from 1.27 for minivan to 2.29 for heavy truck).

Ye et al. (2015) quantified the change of the likelihood of moderate or greater limb injury according to vehicle deformation and type in frontal crashes. Ye et al. used the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) and selected frontal crashes during the calendar years 1998–2010 with no resulting rollover event, ejection or fire. Passenger car, SUV, pickup truck and minivan have been selected in the initial sample. All case occupants were drivers with age greater than 16 years and who were properly belted. A multi-variate logistic regression model was developed for analyzing the associated odds ratios of knee and below knee lower limb injuries in the specified frontal crash conditions.

The risk of AIS 2+ lower limb injury is significantly higher for passenger car drivers in a frontal crash than van drivers (odds ratio: 0.24) in the same accident conditions. There is no significant result for SUV and light trucks. Toepan intrusion also has a significant influence on the risk of lower limb injury. When the intrusion is greater than 2 cm, the risk of lower limb injury is 9.10 times higher than when intrusion is less than 2 cm.

Mass factor
Fredette et al. (2008) compared (using odds ratios) the risk of death or hospitalization in a vehicle (Pickup, Car, SUV and minivan) according to the opponent vehicle type (Pickup, Car, SUV and minivan) and the difference of mass between vehicles (lighter, equal, heavier). The reference accident configuration is a car to car collision, with equal masses for both vehicles.
In most cases, when the subject vehicle has an impact with a heavier vehicle, the risk of death or hospitalization is higher than in a comparable weight car to car collision..

The worst result recorded (a high relative risk) is in collisions where the opponent vehicle is a pickup, which indicatest hat ths vehicle type isparticularly agressive. This result is not the case for passenger cars which appear less agressive for any kind of vehicle (for all mass ratio). For any mass ratio category, the collisions where the opponent vehicle is a car are generally among the least dangerous collisions for drivers.

Anderson et al. (2013) estimated the probability change of fatalities in a struck vehicle in the case of:
- A 1,000 pound (454 kg) increase in striking vehicle weight
- A 1,000 pound (454 kg) increase in struck vehicle weight

Data from the State Data Sytem (SDS maintained by NHTSA), from 8 states[1], are used for the accident analysis. Two-vehicle collisions involving only two light vehicles built after 1980 were selected. Light vehicles are defined as any car, pickup truck, SUV, minivan that weights between 1,500 pounds (680 kg) and 6,000 pounds (2722 kg). They have estimated the conditional expectation of a fatality in the struck vehicle as a function of striking vehicle weight, struck vehicle weight, and a rich set of covariates; and using probit model.

A 1,000 pound (454 kg) increase in weight in the striking vehicle is associated with a statistically significant percentage point increase (0.11%) in the probability of a fatality in the struck vehicle
A 1,000 pound (454 kg) increase in weight in the struck vehicle is associated with a smaller percentage point decrease (-0.097%) in the probability of a fatality in the struck vehicle

Wenzel et al. (2013) estimated the effect of a reduction in light-duty vehicle mass on US societal fatality risk per vehicle mile traveled. Information on all U.S. traffic fatalities in crashes involving model year 2000–2007 light-duty vehicles that occurred between 2002 and 2008, from the Fatality Analysis Reporting System (FARS) were used in the regression analyses. Fatalities include those in both the case vehicles and any of their crash partners, such as medium- and heavy-duty vehicles, motorcycles, bicyclists, and pedestrians. Wenzel et al. replicated the analysis done by Kahane et al.(2012) and have tested other new parameters (collision partner, impact type, etc.)

A 45 kg (100 lb) reduction in mass of light truck vehicles (weight < 2,247 kg) reduces significantly the risk in crashes with object (-1.4%) but increases significantly the risk in crash with heavy light trucks (4.36%). For heavy light truck vehicles (> 2,247 kg), the mass reduction has a small significative effect whatever is the type of crash (from -0.92% to -1.29%).

Footprint reduction in light trucks significantly reduces fatality risk in crashes with pedestrians and cyclists (-1.25%), and with heavier light trucks (-1.70%). And increases the risk for rollover (1.18%) and stationary object (1.97%).

Kahane et al. (2012) also studied the effect of a 100 pound (45 kg) mass-reduction for cars and LTV on the societal fatality risk. "Societal" fatality rates include fatalities to occupants of all the vehicles involved in the collision, plus any pedestrian. Kahane et al. used the Fatality Analysis Reporting System (FARS) database and have selected accidents from 2002-2008 involving LTV and cars whose model year is between 2000-2007. They calculated the societal fatality risk change for five vehicle categories (car < 3,106 pounds – 1409 kg, cars ≥ 3,106 pounds – 1409 kg, CUV and minivan, truck-based LTV < 4,594 pounds – 2084 kg and truck-based LTV ≥ 4,594 pounds – 2084 kg). There is only one result statistically significant. Societal fatality risk increases by 1.56% if mass is reduced by 100 pounds (45 kg) in the lighter cars.

Meta-analysis

Desapriya et al. (2010)attempted to quantify and to compare the risk of fatality for a pedestrian crashed by a LTV or a car. They conducted a systematic review from which 12 articles have been retained. All the articles identified had calculated the odds ratio for the risk of fatal injury for pedestrian in a collision with a LTV compared to a collision with a conventional car. Desapriya et al. combined odds ratios after calculating their standard errors and have weighted them according to the inverse of their variances. The final result is that the risk for a pedestrian of being killed in a crash with a LTV is 1.54 times higher than in a crash with a car.

More results abour pedestrian accidents are avaialble in WP6.

[1] Florida, Kansas, Kentucky, Maryland, Missouri, Ohio, Washington and Wyoming.

3 Supporting Document

3.1 METHODOLOGY

3.1.1 Literature Search strategy

Limitations/ Exclusions for literature serach (all literature search database):

- Search field: ALL (because too few references) or TITLE-ABSTRACT-KEYWORDS (because too many references)
- Expert search
- published: 1990 to current
- Document Type: ALL
- Source type: Journals or Conference Proceedings
- Subject Area: Engineering
- Language: English or French

Table 1: Literature search strategy, database: Sciencedirect

search no.	search terms / operators / combined queries	hits
#1	("light truck" OR "commercial vehicle" OR "van vehicle" OR "MPV" OR "multiple purpose vehicle" OR "light goods vehicle" OR "LGV") AND compatibility	122
#2	("light truck" OR "commercial vehicle" OR "van vehicle" OR "MPV" OR "multiple purpose vehicle" OR "light goods vehicle" OR "LGV") AND crashworthiness	97

Table 2: Literature search strategy, database: Scopus

search no.	search terms / operators / combined queries	hits
#1	tak("light truck" OR "commercial vehicle" OR "van vehicle" OR "MPV" OR "multiple purpose vehicle" OR "light goods vehicle" OR "LGV") AND tak(compatibility)	75
#2	tak("light truck" OR "commercial vehicle" OR "van vehicle" OR "MPV" OR "multiple purpose vehicle" OR "light goods vehicle" OR "LGV") AND tak(crashworthiness)	182

Table 3: Literature search strategy, summary

Total of initial records	476
Total of records after screening	190
Eligible papers	10

3.2 DETAILED ANALYSIS OF STUDY DESIGNS AND METHODS

Table 4: Description of coded studies designs / sample frames - Compatibility (WP6)

Author(s), Year	Sample and study design	Method of analysis	Outcome indicator	Main result
Anderson et al., 2013	Police-reported accidents for eight states: Florida, Kansas, Kentucky, Maryland, Missouri, Ohio, Washington and Wyoming. Passenger car versus LTV vehicle collisions	Probit regression	Percentage change in the probability of fatalities or serious injuries in the struck vehicle	Effect of vehicle weight on fatalities and serious injuries in struck vehicle. A 1,000 pound increase in weight in the striking vehicle increases significantly the probability of fatalities or serious injuries in the struck vehicle. Also true, when the striking vehicle is a Light Truck
Xin et al., 2015	Frontal crashes during the calendar years 1998–2010 with the principal direction of force (PDOF) between 11 and 1 o'clock (PDOF = 30), and no resulting rollover event, ejection or fire. All case occupants were drivers with age greater than 16 years and who were properly belted. Vehicle model years were restricted to 1998–2011. Vehicles were categorized into four body types, namely passenger cars, SUVs, light vans, and pickup trucks (<5000 kg curb weight).	Multi-variate logistic regression	Odds ratio (Risk of lower limb AIS2+ injury)	Toepan intrusion greater than 2 cm was significantly associated with AIS 2 + knee and below knee injury. Relative to passenger cars, vans exhibited a significant decrease in sustaining lower limb injury, followed by SUVs though the result was non-significant whereas light trucks showed no such protective association.
Dekra et al., 2013	GIDAS-database, the database of the German Insurers Accident Research (UDV), the DEKRA database	Descriptive analysis	Percentage	In accordance with their road usage, passenger cars are the most frequent counterparty in the event of an accident, both with other passenger cars and Light Commercial Vehicles. Their frequency is approximately 50%. In 30% of the cases the vehicles collide with unprotected road users such as pedestrians or cyclists
Ossiander et al., 2010	The study used a case-control design. From each eligible fatal crash, all fatalities were selected as cases, and from each eligible non-fatal crash, one person was selected as a control. Cases from the Fatality Analysis Reporting System (FARS). The geographic coverage includes all 50 states, Washington, DC, and Puerto Rico. Controls from the 1990-2008 General Estimates System (GES). Both cases and controls were selected from collisions occurring between 1990 and 2008 in which two passenger vehicles (cars, pickups, SUVs, or vans) and no pedestrian were involved, and in which both vehicles were model year 1980 or later.	Logistic regression	Odds ratio and relative risk	Occupants of all 6 categories of light trucks had a lower risk than car occupants of being killed if they were in a crash. The safest type of light truck was full-size pickup. Among light trucks, compact SUVs offered the least protection to their occupants. Full-size SUVs, full-size vans, and full-size pickups each offered significantly better protection to their occupants than compact SUVs, minivans, or compact pickups. These results suggest that LTVs protect their own occupants better than cars do, but impose excess risk on occupants of the other vehicle in a crash.
Lenard et al., 2004	The data are derived from two main sources. The source involves mass analysis of crashes involving LGVs recorded in the national British STATS19 accident database for 1994 to 2000. Car versus LGV collisions	Absolute proportion	Agressivity index and relative injury risk	Using both the aggressivity index and the relative injury risk index, it can be seen that in car-to-LGV crashes, it is the drivers of cars who are at greatest risk of injury at every level of severity.

Fredette et al., 2008	Canada - National Collision Database. This database contains information on all collisions reported by police in Canada. This made it possible to analyse two-vehicle collisions occurring between 1993 and 2001 in seven Canadian provinces or territories: Alberta, Prince Edward Island, Ontario, Quebec, New-foundland, Saskatchewan and Yukon. These collisions exclude the ones involving motorcycles, bicycles, snowmobiles, or all-terrain vehicles, and those where the type of one or both vehicles involved was missing. Observations where the severity of the injuries of the driver is missing were also deleted from the sample.	Logistic regression was used to model the risk of driver death or major injury (defined has being hospitalized).	Odds ratio	Pickup trucks, minivans and sport utility vehicles (SUVs) are more aggressive than cars for the driver of the opponent vehicle and more protective for their own drivers. The effect of the pickups is more pronounced in terms of aggressivity.
Kahane et al., 2012	The analyses comprised MY 2000-2007 cars and LTVs in CY 2002-2008 crashes. Fatality rates were derived from FARS data, 13 State crash files, and registration and mileage data from R.L. Polk.	Logistic regression	Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant	This analysis finds that societal fatality risk increases by 1.56 percent if mass is reduced by 100 pounds in the lighter cars. This is the only statistically significant effect found in the current analysis; it is the only one with confidence bounds that exclude zero. There are non-significant increases in societal fatality risk for mass reduction in the heavier cars and the lighter truck-based LTVs. There are non-significant societal benefits for mass reduction in CUVs, minivans, and the heavier truck-based LTVs.
Gabler et al., 2003	The analysis was based upon the 1997-2001 Fatality Analysis Reporting System (FARS) and the 1997-2001 NASS General Estimates System (GES). Occupant fatality counts were obtained from FARS. For the purposes of this study, only side impacts involving two vehicles were analyzed. Only cases in which both vehicles were either a car or an LTV were included. Only driver fatalities are considered	Proportion	Ratio of striking-to-struck driver fatalities resulting from left side impacts	Side impact crashworthiness in cars of model year 1997-2001 was found to be significantly better than the side impact crashworthiness of cars of model years 1980-89. This improvement in crashworthiness was noted when these vehicles were struck by cars and every class of LTV
Desapriya et al.,2010	A search for the studies in bibliographic databases that included ATI (Australian Transport Index); Cochrane Injuries Group Specialized Register; EMBASE; ERIC; MEDLINE; National Research Register; PsycINFO; Road Res (ARRB); SIGLE; Science (and Social Science) Citation Index; TRANSPORT (NTIS, TRIS, TRANSDOC, IRRD). Web sites of traffic and road accident research bodies, government agencies, and injury prevention organizations were searched for grey literature. The specific objective of this systematic review and meta-analysis is to quantify and compare the impact of light truck vehicles (LTVs) versus conventional cars on pedestrian fatal injury	Meta-analysis	Odds ratio	The risk for pedestrians of sustaining fatal injury is 50 percent greater in collisions with LTVs than in collisions with conventional cars

Wenzel et al., 2013	Information on all U.S. traffic fatalities in crashes involving model year 2000–2007 light-duty vehicles that occurred between 2002 and 2008, from the Fatality Analysis Reporting System (FARS) were used in the regression analyses.	Logistic regression	Estimated effect of a 45-kg reduction in mass or a 0.09-m² reduction in footprint on U.S. societal fatality risk, by vehicle and crash type.	In general, the estimated effects on risk are smaller for light trucks than for cars, and there are more cases in which mass reduction is estimated to reduce risk, although the estimates are often small and not statistically significant. Mass reduction is associated with a statistically significant reduction in risk in lighter truck crashes with objects, and heavier truck rollovers; but (statistically insignificant) increases in risk in lighter truck rollovers and heaver truck crashes with objects. As with light cars, the biggest estimate of mass reduction in lighter trucks is in crashes with a heavier light truck, with a 4.4% increase in risk

3.3 EXPLORATORY ANALYSIS OF RESULTS

Table 5: Overview of results of coded studies - compatibility (WP6)

Author(s), Year , country	Risk factor	Study type	Outcome variable	Effects for road safety	Main outcome - description
Dekra et al., 2013, Germany	LGV collision description	Descriptive analysis	Collision partner	↓	In accordance with their road usage, passenger cars are the most frequent counterparty in the event of an accident (against LGV). Their frequency is approximately 50%. In 30% of the cases, the vehicles collide with unprotected road users such as pedestrians or cyclists.
Lenard et al., 2004, UK	Agressivity index	Ratio	Road users injured in the other vehicle / all injured road users in the accidents	↓	At all levels of severity, LGV is more agressive for passenger car road users than passenger car is for LGV road users.
Lenard et al., 2004, UK	Relative injury risk	Ratio	Road users injured in the subject vehicle / road users injured in the other vehicle	↓	The risk of injury at all levels of severity is greater in cars than in vans.
Gabler et al., 2003, USA	Struck car - side impact - model year 1980-89	Ratio	Fatalities in the struck passenger car	↓	For every driver who dies in a striking LTV, 43 side struck car drivers are fatally injured when the struck car is of model year 1980-89.
Gabler et al., 2003, USA	Struck car - side impact - model year 1997-2001	Ratio	Fatalities in the struck passenger car	↑	By contrast, if the struck car is of model year 1997-2001, for every fatally injured driver of a striking LTV, only 17 side-struck car drivers are killed.
Ossiander et al., 2010, USA	Self protection in passenger cars and LGV	Logistic regression	Fatality in the vehicle	↓	Light trucks had a lower risk than car occupants of being killed if they were in a crash. The safest type of light truck was full-size pickups. Among light trucks, compact SUVs offered the least protection to their occupants, with an odds ratio of 0.76 (95% CI 0.66-0.87). Full-size SUVs, full-size vans, and full-size pickups each offered significantly better protection to their occupants than compact SUVs, minivans, or compact pickups.
Ossiander et al., 2010, USA	Partner protection in passenger cars and LGV	Logistic regression	Fatality in the vehicle	↓	Vehicle occupants in a crash in which the opposing vehicle was a light truck were at higher risk of dying compared to crashes in which the opposing vehicle was a car. The most dangerous light trucks to crash with were full-size vans, and the least dangerous were compact pickups.

Ossiander et al., 2010, USA	Self protection and partner protection (~compatibility) in passenger cars and LGV	Logistic regression	Fatality in the accident	↓	All of the relative risks for the net effects are 1.0 or greater, suggesting that a randomly selected occupant is at least as likely, and usually more likely, to be killed in a crash involving an LTV as in a crash involving two cars.
Fredette et al., 2008, Canada	Self protection in passenger cars and LGV	Logistic regression	Fatality in the vehicle	↓	The risk of injuries is greater in a car than in a LTV when they crashed another vehicle.
Fredette et al., 2008, Canada	Partner protection in passenger cars and LGV	Logistic regression	Fatality in the vehicle	↓	The risk of injuries is greater in a vehicle crashed by a LTV than a by a car.
Fredette et al., 2008, Canada	Self protection and partner protection (~compatibility) in passenger cars and LGV	Logistic regression	Fatality in the accident	↓	- Most of the odds ratios significantly greater than 1 are associated with collisions where the driver's vehicle had a smaller mass than the other vehicle. Similarly, the odds ratios significantly less than 1 are associated with collisions where the driver's vehicle was heavier than the other vehicle. - The aggressivity of pickup trucks is clearly established. For any mass ratio category, the most dangerous collisions are always the ones where the other vehicle is a pickup. Indeed, when we look only at the point estimates of odds ratios, we see that the four types of collisions where the other vehicle is a pickup are always the most dangerous collisions. In addition, it is interesting to note that, when passengers cars are involved, the aggressivity of pickup trucks is comparable to the extra protection of having a car at least 20% heavier. - The low aggressivity of passenger cars is also clearly established. For any mass ratio category, the collisions where the other vehicle is a car are generally among the least dangerous collisions for drivers. - Collisions involving vehicles of the same type are not necessarily less dangerous: for any mass ratio category, the most dangerous collisions are those involving two pickups. - When not colliding with pickups, pickups are highly protective.For any mass ratio category, pickup drivers are generally less at risk than drivers of other vehicle types.
Xin et al., 2015, USA	Risk of AIS 2+ lower limb injury according to vehicle type	Logistic regression	Lower limb injury	↓	Relative to passenger cars, vans exhibited a significant decrease in sustaining lower limb injury, followed by SUVs though the result was non-significant, whereas light trucks showed no such protective association.
Xin et al., 2015, USA	Toepan intrusion	Logistic regression	Lower limb injury	↓	Toepan intrusion greater than 2cm was significantly associated with AIS 2+ knee and below knee injury.
Anderson et al., 2013, USA	1,000 pound increase in the striking vehicle	Probit regression	Percentage point change in the probability of a fatality and/or a serious injury in the struck vehicle	↓	A 1,000 pound increase in weight in the striking vehicle is associated with a statistically significant percentage point increase in the probability of a fatality in the struck vehicle.
Anderson et al., 2013, USA	1,000 pound increase in the struck vehicle	Probit regression	Percentage point change in the probability of a fatality and/or a serious injury in the struck vehicle	↑	A 1,000 pound increase in weight in the struck vehicle is associated with a smaller percentage point decrease in the probability of a fatality in the struck vehicle.
Kahane et al., 2012, USA	Mass reduction	Logistic regression	Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint Constant	↓	Only the 1.56 percent risk increase in the lighter cars is statistically significant. There are non-significant increases in the heavier cars and the lighter truck-based LTVs and non-significant societal benefits for mass reduction in CUVs, minivans, and the heavier truck-based LTVs.

Wenzel et al., 2013, USA	A 45 kg reduction in mass	Logistic regression	Societal fatality risk	-	Mass reduction is associated with a statistically significant reduction in risk in lighter truck crashes with objects, and heavier truck rollovers. As with light cars, the biggest estimate of mass reduction in lighter trucks is in crashes with a heavier light truck, with a 4.4% increase in risk.
Wenzel et al., 2013, USA	A 0.09 m^2 reduction in footprint	Logistic regression	Societal fatality risk	-	A reduction in light truck footprint tends to correlate with an increase in risk, although the estimated increases are small and often not statistically significant. However, contrary to cars, footprint reduction in light trucks significantly reduces fatality risk in crashes with pedestrians and cyclists, and with heavier light trucks.
Desapriya et al.,2010, Meta-analysis (USA, The Netherlands, Australia, Canada)	Collision between a LTV and a pedestrian	Meta-analysis	Risk of fatal injury in pedestrian collison with LTV compared to passenegr cars	↓	Compared to those hit by conventional passenger cars, pedestrians hit by LTVs were more likely to suffer injuries

3.4 REFERENCES

A detailed list of studies considered are listed below:

Abdel-Aty, M., Abdelwahab, H. (2004). Analysis and Prediction of Traffic Fatalities Resulting from Angle Collisions Including the Effect of Vehicles' Configuration and Compatibility. Accident Analysis and Prevention, 36-3, pp.457-469.

Anderson, M., L., Auffhammer, M. (2013). Pounds that kill: The external costs of vehicle weight. Review of Economic Studies, 81-2, pp. 535-571

DEKRA, BAST, UDV, VDA (2013). Project Report Safety of Light Commercial Vehicles.

Desapriya, E., Subzwari, S., Sasges, D., Basic, A., Alidina, A., Turcotte, K., Pike, I. (2010). Do light truck vehicles (LTV) impose greater risk of pedestrian injury than passenger cars? a meta-analysis and systematic review. Traffic Injury Prevention, 11, pp. 48-56

Fredette, M., Mambu, L. S., Chouinard, A., Bellavance, F. (2008). Safety impacts due to the incompatibility of SUVs, minivans, and pickup trucks in two-vehicle collisions. Accident Analysis & Prevention, 40-6, pp. 1987-1995.

Gabler, H., C. (2003). The evolution of side crash compatibility between cars, light trucks and vans. SAE Technical Papers, 2003-01-0899

Ye, X., Poplin, G., Bose, D., Forbes, A., Hurwitz, S., Shaw, G., Crandall, J. (2015). Analysis of crash parameters and driver characteristics associated with lower limb injury. Accident Analysis & Prevention, 83, pp. 37-46

Kahane, C., J. (2012). Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000—2007. NHTSA technical report - DOT HS 811 665

Lenard, J., Frampton, R., Kirk, A., Morris, A., Newton, R., Thomas, P.,Fay, P.A. (2004). Accidents, injuries and safety priorities for light goods vehicles in Great Britain. Journal of Automobile Engineering, 218-6, pp. 611-618

Ossiander, E., M., Koepsell, T., D., McKnight, B. (2010). Crash fatality and vehicle incompatibility in collisions between cars and light trucks or vans. Injury Prevention;20, pp.373-379

Wenzel, T. (2013). The estimated effect of mass or footprint reduction in recent light-duty vehicles on U.S. societal fatality risk per vehicle mile traveled. Accident Analysis & Prevention, 59, pp. 267-276