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Truck-bicycle safety: an overview of methods of study, risk factors and research needs

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Abstract

The growing numbers of cyclists either injured or killed in accidents caused by trucks have been generally regarded as a safety problem since the 1980s (McCarthy & Gilbert, Accident Analysis & Prevention 28:275–279, 1996). Indeed, in several countries, cyclists killed by a truck represent almost 30% of all cycling fatalities (Pokorny et al., Transportation Research Procedia, 25, 2017). Whilst increasing attention has been paid to this topic by road safety researchers, a scoping review of the current research has been lacking. The aim of this paper is therefore to present a scoping review of the research literature related specifically to truck-bicycle safety, including both safety analysis and measures. Out of the 1,530 documents initially identified in the first phase of this search, 43 were selected for the final analysis. The review outlines the prevailing topics studied and research methods utilized for exploring these topics. Furthermore, findings regarding accident risk factors are summarised, as the information they provide presents us with a key for implementing more efficient safety measures. Additionally, suggestions for future research needs are identified.

Keywords: Trucks, Bicycles, Safety, Risk factors, Safety measures

1 Introduction

Across the world, the number of cyclists has been increasing in many cities [1]. People are encouraged and motivated to cycle, as this type of activity improves their health, reduces the negative effects of motorised traffic, and creates more liveable and vibrant cities. At the same time, recent trends in land use and urban planning, economic development, and consumer demand have contributed to increasing the numbers of trucks driving around in these same cities [2, 3]. Because of the increasing traffic volume of trucks and bikes, their routes frequently overlap and intersect with each other in constrained urban spaces. For example, in New York City alone, 15% of the bicycle networks and 11% of the truck networks are currently overlapping [4]. Thus, encounters between trucks and bikes are relatively common.

The mere presence of trucks has been shown to contribute to higher accident risk for cyclists [5, 6] and truck-bicycle accidents usually have more severe consequences for the cyclists involved than any other types of accidents [7–10]; consequently, trucks are overrepresented in fatal bicycle accidents [11]. According to the EU accident database CARE, 283 cyclist fatalities caused by truck accidents were recorded in 2015 in the EU, which is almost 14% of all cycle fatalities in Europe. In several EU countries, this percentage rises to nearly 25% (e.g. in Denmark, Estonia, Ireland, Slovakia) [12]. Studies of fatal bicycle accidents in London have identified heavy trucks as the most frequently involved vehicle category in accidents resulting in cyclists' deaths over the past two decades [8, 13, 14].

Less severe encounters, including conflicts, have negative consequences as well. When cyclists become involved in conflicts with trucks, their fear level significantly increases, which can affect their overall perception of risk [15, 16]. In a crowded urban environment, a truck's presence can significantly affect a bicyclist's perceived level of comfort [17]. Therefore, frequent interactions with trucks have the potential to deter people from cycling (both in general and in avoidance of specific areas).

Given the current promotion of urban cycling and increased safety concerns related to vulnerable road users, the topic of truck-bicycle safety has continued to grab

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attention from the public, media and trucking industry. A range of safety measures have been introduced in many countries to increase the safety level between bicycles and trucks, including targeted legislation, more truck safety equipment, increased awareness among both cyclists and truck drivers, and safer infrastructures. At the same time, research on the topic has grown considerably, resulting in an increased body of literature. The results of this research have been summarised in several reports [18]; however, there has been a lack of a scoping review of this literature. The aim of this paper is therefore to review the research literature related specifically to truck-bicycle safety,[1] including both safety analysis and measures, in order to outline prevailing topics and the research methods utilised to study them. Furthermore, the findings regarding accident risk factors (i.e. factors that contribute to the occurrence of truck-bicycle accidents) are summarised, as this information presents us with a key for implementing efficient safety measures. Additionally, suggestions for future research needs are identified.

2 Methodology

The type of review is a scoping review. As described by Arksey and O'Malley, a scoping review outlines the research topic, summarizes and disseminates research findings, and identifies research gaps in the existing literature, as opposed to describing research findings in detail [19]. The methodological approach to the search strategy and the review itself are described below.

2.1 Search strategy

The search was conducted in October 2018; its timespan was set to the period 1990–2018. The scholarly databases Scopus (Elsevier) and Transport Research International Documentation (TRID) were searched for the titles and abstracts of written English studies using the combination of the following key words (applying the Boolean operators "and"/"or"): *truck*; hgv; heavy vehicle*; lorr*; freight; safety; blind; vulnerable; cycl*; bike*; bicyc*; conflict*; accident*.* The studies were required to be made available in full-text in digital format in order to be included in this review.

The TRID database was noted to contain grey literature (i.e. standards, reports and guidelines) not published in Scopus. While grey literature is not traditionally considered to fall within literature review parameters, there has been recognition of its value and a growing acceptance of its inclusion [20, 21]. Increased digitization of databases has allowed for easier access to such literature, and the deliberate selection of material considered within the review allows for the control of source expertise. Within this review, grey literature in the form of conference papers and reports published by reputable research institutes and universities was considered to broaden the scope of the review beyond the relatively low number of published peer-reviewed journal papers in the field of truck-bicycle safety.

After excluding duplicated records, the studies were checked for their relevance by first evaluating the title and then the abstract and/or full text. Only studies that focused specifically on truck-bicycle safety were selected, and their bibliographies were scanned for additional references. As a result of this process, a total of 43 studies were identified (see Fig. 1 for the search strategy's pathway diagram).

2.2 Review process

The studies were categorised according to their main topic into four categories: accident analysis, non-accident analysis (i.e. conflict and behavioural analysis), safety measures, and others. If a study involved more than one main topic, each of these topics was considered separately (e.g. a study that applied accident analysis along with an evaluation of a safety measure contains two main topics – accident analysis and safety measures). Basic characteristics of each study (e.g. analytical method, sample size), were summarised in tables for each main topic category and further described. Risk factors for each topic category were identified and assigned to the basic elements of the road transport system (i.e. road users, infrastructure, vehicle and management). At the end, suggestions for future research needs were identified and summarised.

3 Results

3.1 Description of the sample

In total, 43 studies (21 journal papers, 11 conference papers and 11 reports) were identified for the analysis. The vast majority of studies (84%) were published from 2010 onwards (see Fig. 2). While the review was open to considering studies from 1990 onwards, no studies published prior to 2003 were found to be relevant. Most of the studies originate in the UK ($n = 16$), Germany ($n = 7$) and the USA ($n = 7$). As the search was limited to literature published in English, it is acknowledged that the results of the review might be biased towards literature from countries more likely to publish in the English language.

The main topics discussed within the reviewed studies were categorised into the following groups:

- accident analysis ($n = 14$)
- non-accident analysis ($n = 12$)
- safety measures ($n = 25$)
- other ($n = 5$)

As described in the methodology, a study could be categorised into more than one group; thus, the numbers above include double-counting. The findings for each of these four groups are summarised in paragraphs 3.2.-3.5.

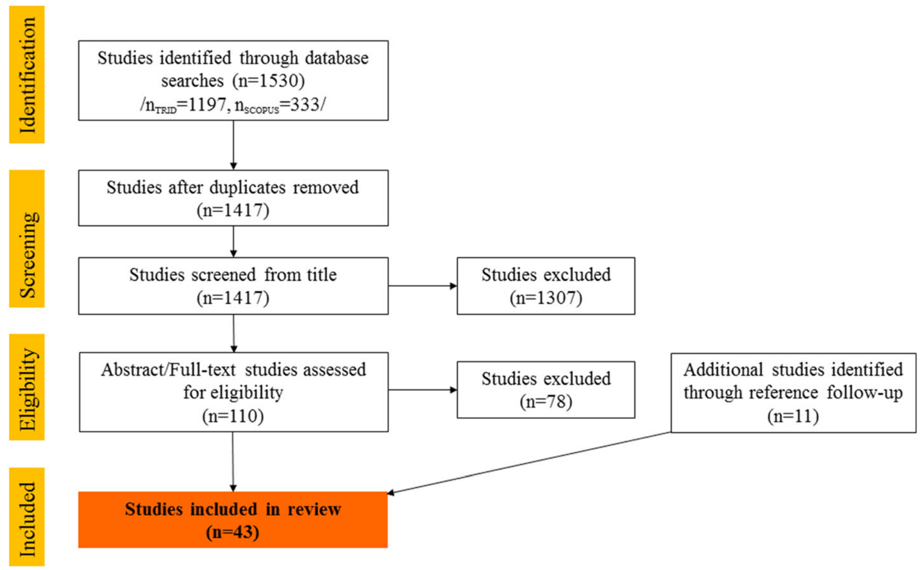

Fig. 1 Pathway diagram of the review's included and excluded studies

3.2 Accident analysis

Fourteen studies that contain an analysis of truck-bicycle accidents (referred to hereafter as TCA) were identified. Their characteristics are summarised in Table 1. There are three common types of analysis in the sample – in-depth, accident data and forensic. Three studies combine both in-depth and accident data analysis. Several studies apply accident analysis as a basis for consequent research (e.g. to explore a safety measure's potential), while in the other studies, accident analysis is the main objective.

Nearly all of the studies apply descriptive statistics to analyse their data, while only one study applies statistical modelling (i.e. binary logistic regression - [31]). Additionally, only one study attempted to evaluate an exposure and calculate a relative accident risk [18].

The average sample size for accident data analysis is 306 accidents (min 61, max 755, st.d. 221), while it is 54 accidents for in-depth analysis (min 5, max 142, st.d. 51). The average study period is 6.3 years (st.d. 4,4) for accident data analysis and 5.1 years (st.d. 3,8) for in-depth analysis. Accidents that are connected with blind spots and right-

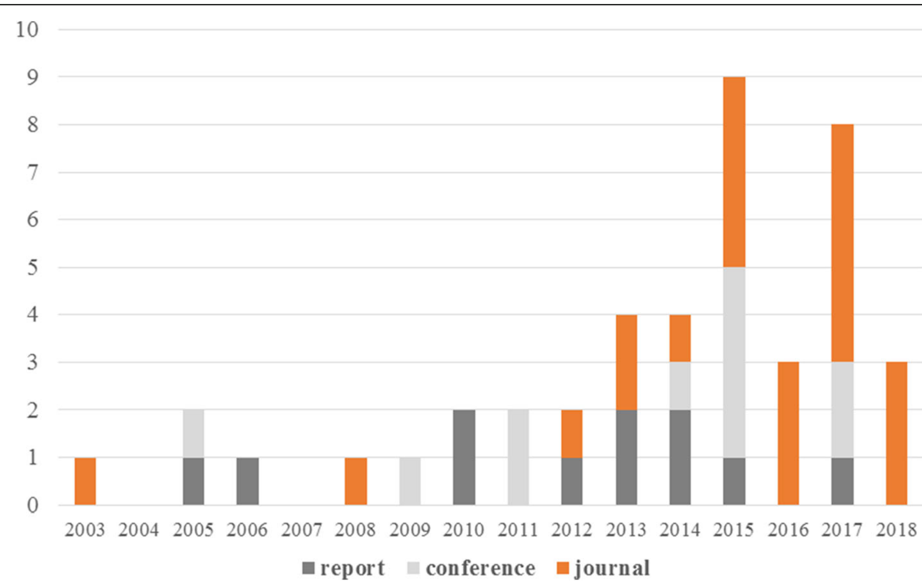

Fig. 2 Annual numbers of published studies

Table 1 Characteristics of accident studies

Study	Type	Data source	Method	Aim	Accident type	Sample size	Time period (years)	Truck type
Klintschar et al., 2003 [22]	Forensic	Investigation reports	Description of the case	Describe the mechanism of the specific accident type	Dragging accident	1	not relevant	Long trailer
Niewoehner & Berg, 2005 [23]	In-depth	DEKRA database[a]	Descriptive statistics	Explore the characteristics of accidents and suggest safety measures	Turning accidents	45	1	Goods vehicles over 3,5 t
Fenn et al., 2005 [24]	Accident data	STATS 19 database[a]	Descriptive statistic	Investigate blind spot related accidents	Blind spot accidents	503	7	Goods vehicle over 7,5 t
	In-depth	HVCIS database[a]				17	3	
Cookson & Knight, 2010 [25]	Accident data	STATS 19 database [a]	Descriptive statistics	Assessing the effects of sideguards	Trucks overtaking and turning left vs. cyclists	352	3	Heavy Goods Vehicle
	In-depth	HVCIS database[a]				142	10	
Gelino et al., 2012 [26]	Accident data	Police database	Descriptive statistics	Assess the safety situation	Truck-bicycle accidents	61	11	Large trucks
Helman et al., 2013 [18]	Accident data	STATS19[a] database	Descriptive statistics and exposure analysis	Understand the relative risk represented by construction vehicles	Truck-bicycle accidents	311	4	Construction vehicles
Johannsen et al., 2015 [27]	In-depth	GIDAS database[a]	Detailed reconstruction	Improve understanding of pre-accident dynamics	Turning accidents	5	1	Trucks, lorries and vans
Seiniger et al., 2015 [28]	In-depth	GIDAS and UDV databases[a]	Descriptive statistics	Analysis of speeds, behaviour, infrastructure	Turning accidents	120	unknown	unknown
Conway et al., 2016 [4]	Accident data	Police database	Geospatial analyses	Explore infrastructure and demand characteristics indicative of truck-bicycle conflicts	Truck-bicycle accidents on specific routes	122	3	Large (6+ tires) and commercial vehicles (4 tires)
Britton, 2016 [29]	Accident data	FARS database[a]	Descriptive statistics	Explore characteristics of fatal accidents	Fatal truck-bicycle accidents	78	1	Large trucks
Malczyk & Bende, 2017 [30]	In-depth	UDV database[a]	Descriptive statistics	Explore potential for electronic turn-assistance	Truck-bicycle accidents	62	6	Vehicle over 12 t
Pokorny et al., 2017 [31]	Accident data	Police database	Descriptive statistics, binary logistic model	Explore characteristics and contributory factors of accidents	Truck-bicycle accidents	271	15	Vehicle classified by police as truck, semitrailer, tanker, 1-axe trailer or 2-axe trailer
	In-depth	NPRA database[a]	Descriptive statistics		Fatal truck-bicycle accidents	13	10	
Richter & Sachs, 2017 [32]	Accident data	Police database	Descriptive statistics	Gain knowledge to improve infrastructure design	Turning accidents	755	6	Van, delivery truck, truck without trailer, semitrailer truck
Talbot et al., 2017 [33]	In-depth	Police investigation files	Descriptive statistics	Identify the contributory factors	Truck-bicycle accidents	27	5	Trucks over 3,5 t

[a]*DEKRA* A company accident database, *GIDAS* German in-depth accident study, *UDV* German Insurers accident database, *STATS 19* UK National accident database based on police records, *HVCIS* Police fatal accident database, *FARS* Fatality analysis reporting system, *NPRA* Norwegian Public Road Administration database

turning trucks (left-turning in the UK) are specifically considered in six studies (referred to hereafter as turning-accidents). The definition of the term *truck* is not consistent within the studies. A number of studies provide a specific definition (e.g. large-6+ tires-commercial vehicles), while others provide only a vague definition (e.g. heavy goods vehicle).

3.2.1 Risk factors

Several risk factors were identified within the reviewed accident studies. These related to *road users* are cyclists' incorrect assumptions about the truck driver's ability to see them and about truck manoeuvres [23], improper adjustment and usage of blind spot mirrors by drivers [24], lack of awareness regarding blind spot issues by both cyclists and drivers [23], lack of visual contact and communication between driver and cyclist (communication breakdown) [31], risky behaviour of both cyclists and truck drivers (e.g. using phones, overtaking a truck from the inside; truck reversing on cycle paths without any outside assistance; risky overtaking of cyclist or unexpected truck turning manoeuvres) [24, 31, 33]. The risk factors related to *infrastructure* are complexity of urban intersections [33], objects limiting visibility (e.g. greenery; traffic signs; advertisements) [23, 31], road narrowing (e.g. due to traffic calming; parked vehicles; pedestrian facilities or road works) [31, 33], road surface conditions [31] and unsafe infrastructure layout (e.g. road moved due to construction; an alignment of cycle paths encouraging higher speeds; simultaneous green phase; broad strip of grass between traffic lane and cycle path; a traffic lane shared by cyclists moving straight ahead with adjacently turning trucks; a cycle lane or path ending at an intersection without continuing further; unsafe design of cycle advanced box; confusing road markings; pedestrian guard rails and kerbstones preventing cyclists' escape) [23, 31–33]. The risk factor related to *vehicle* are design of construction and rigid trucks [18, 23, 31], insufficient truck equipment (e.g. lack of Class VI mirrors) [33] and limited visibility (both direct and indirect) from the truck, particularly during turning manoeuvres [23, 24, 27, 33]. The risk factors related to *management* are planning and management practices contributing to the overlap of bike and truck routes [4, 26], the overlap of truck and cyclist peak traffic at specific times of the day/week [33], the lack of safety near the construction sites [31] and unsuitable locations of areas with higher demand for trucks [4].

3.3 Non-accident analysis

Non-accident analyses include studies of truck-bicycle conflicts and behavioural aspects related to truck-bicycle encounters. Twelve such studies were identified. Three studies included both conflict and behavioural analysis, resulting in a total of five conflict and ten behavioural studies (with double-counting). These characteristics have been summarised in Table 2.

3.3.1 Conflict studies

All five studies define conflict by using the concept of an evasive action subjectively acknowledged by the researcher. Data on conflicts were collected either by an observation in real traffic using a camera or a human observer (3 studies), or by a retrospective postal or online survey (2 studies). To evaluate the data, three studies used descriptive statistics, while two studies applied a correlation and regression analysis. The three studies that used observations recorded in total 98 conflicts within 277 observation hours. Each study evaluated different types of conflicts (i.e. turning; parking; delivery manoeuvres). The two studies that collected data from surveys had a relatively high number of respondents (311 drivers and 631 cyclists), who reported in total 304 and 378 conflicts respectively experienced during the last 12 months. One of these studies investigated truck-bicycle conflicts in general, while the other one examined a specific type of conflict.

3.3.2 Behavioural studies

The 10 identified behavioural studies focused either on truck drivers ($n = 4$), cyclists ($n = 3$) or on both drivers and cyclists ($n = 3$). People's ability to deal with additional equipment in trucks was their most common topic of interest ($n = 4$). The methods of data collection varied greatly, including postal and online surveys, interviews, observations, experiments, assisted driving and simulations. The average number of respondents was 637 (min 3, max 4596), with the lowest numbers in experiments and assisted driving, while the highest was in online surveys. To evaluate the data, ANOVA tests and descriptive statistics were typically applied.

3.3.3 Risk factors

Several risk factors were identified within the reviewed non-accident studies. These related to *road users* are young age, as adolescent cyclists have difficulties practicing safe performance in blind spot areas near trucks [37], bbehavioural adaptation to safety measures [34], combination of factors affecting the likelihood of driver errors [18], cyclists' behaviour not conforming to normal expectations [18], driving in unfamiliar locations [18], gender (female cyclists might not correctly differentiate between the risks associated with inside and outside overtaking of trucks compared to male cyclists) [35], reaction time (slower reaction of drivers to objects visible only in mirrors compared to direct viewing through the front windscreen) [39] and time pressure related to delivery time slots for truck drivers [18]. These related to *infrastructure* are insufficient layout of loading area [40], lack of recognizable and comprehensible

Table 2 Characteristics of non-accident studies

Study	Type	Aim	Data collection	Sample size	Evaluation method	Definition of conflict	Truck type
Fenn et al., 2005 [24]	Behavioural / Conflict	Examine drivers' experiences related to close proximity mirrors	Postal survey	311 drivers	Descriptive statistics	Impression of close calls (barely avoiding an accident)	not reported
FDS International (2010) [34]	Behavioural	Evaluate the behaviour related to roadside mirrors	Interviews	51 drivers 20 cyclists	Descriptive statistics	not relevant	Long goods vehicle
Frings et al., 2012 [35]	Behavioural	Examine gender differences in risk perception associated with various cycling maneuvers near trucks	On-line questionnaire	4596 cyclists	Variance analysis (ANOVA); chi-square analysis	not relevant	Truck over 3,5 t
Conway et al., 2013 [36]	Conflict	Assess cyclists' exposure to multimodal conflict in urban on-street bicycle lanes	Direct observations	50 h 35 sites 25 conflicts	Bivariate correlation analyses	To avoid a collision, cyclist must exit the bicycle lane or stop	Trucks and vans
Twisk et al., 2013 [37]	Behavioural	Evaluate awareness programs by examining the decisions of young cyclists when in blind spot areas	Table-top models Quasi-experimental design	62 cyclists	Mixed design ANOVA	not relevant	not reported
Helman et al., 2013 [18]	Behavioural	Assessment of drivers' tasks while turning left; assessment of driver errors	Accompanied driving followed by short interviews	3 drivers	Cognitive task analysis	not relevant	Construction vehicles
Milner et al., 2016 [38]	Behavioural	Study behaviour related to direct and indirect vision, Improve the understanding of visual processing	Literature review, road user surveys, laboratory experiments	117 drivers 129 cyclists	Descriptive statistics and qualitative analysis	not relevant	not reported
Mole & Wilkie, 2017 [39]	Behavioural	Examine whether mirrors delay driver responses	Simulation of driving tasks	41 drivers	Mixed model ANOVA	not relevant	not reported
Pitera et al., 2017 [40]	Conflict	Conduct safety evaluation of loading area located next to busy cycle street	Observation with camera	100 h 1 site 2 conflicts	Descriptive statistics	Presence of an evasive action	Delivery truck (excluding vans)
	Behavioural	Investigate road users' understanding of a safety measure	Intercept interviews Camera	39 cyclists 5 drivers		not relevant	
Richter & Sachs, 2017 [32]	Behavioural	Examine the driving and gaze behaviour when using turn-off assistant	Simulation of routes	48 drivers	Descriptive statistics	not relevant	Van, delivery truck, truck without trailer, semitrailer truck
	Conflict	Observe the behaviour and conflicts in right-turning maneuvers	Observation with camera	129 h 43 sites 71 conflicts		not reported	
Abadi & Hurwitz, 2018 [17]	Behavioural	Investigate cyclists' perceived level of comfort near urban loading zones	Online questionnaire	342 cyclists	Repeated-measures ANOVA, cluster analysis	not relevant	not reported
Pokorny et al., 2018 [41]	Conflict	Investigate cyclists' involvement in conflicts with trucks (frequency, type and characteristics of conflicts)	On-line questionnaire	631 cyclists	Descriptive statistics, multinomial logistic regression	A near collision, but due to the quick reactions of the cyclist and/or driver, accident averted	Large road vehicle used for carrying or pulling goods or materials

intersection design [32], narrow roads and tight corners [18], unseparated signalling phases for turning trucks and straight riding cyclists, particularly when traffic volumes and speeds are high [32] and specific configuration of bicycle lane and parking lane [36]. One factor related to management is related to land use characteristics, that affect the flow of trucks and cyclists [36].

3.4 Safety measures

In total, 25 studies that develop, test or evaluate truck-bicycle safety measures were identified. Their characteristics are summarised in Table 3.

Sixty percent of the studies discuss solely the measures related to trucks 'equipment, particularly developing and/or testing a novel type of measurement using field tests, experiments, modelling or simulations. Most of these measures ($n = 10$) were active safety measures, aiming at blind spot elimination and cyclist detection in the proximity of trucks. Five studies evaluate the potential effects of implementing vehicle-related measures based on a change in legislation (e.g. retrofitting certain types of trucks with blind spot mirrors). Six studies relate to infrastructure, education and management-related safety measures.

3.4.1 Risk factors

Several risk factors were identified within the reviewed non-accident studies. These related to *road users* are behavioural adaptation to safety measures [34], efficiency of mirrors highly depends on the truck driver's alertness [50], challenging scanning of multiple mirrors in high workload situations [55] and truck drivers' overload with physical and cognitive tasks, which affect the driving performance, particularly in turning manoeuvres [51, 57]. These related to *vehicle* are frequent false positive alarms of an active safety system (they are annoying for truck drivers and can cause them to avoid using this system) [50], off- tracking of large trucks in turning manoeuvres (i.e. the last axle is not able to follow the first axle) results in the truck encroaching on the area where cyclists travel [53, 57], sound insulation of the truck cab can contribute to the reduction in drivers situational awareness around their truck [47] and a typical detection system warns only one of the two participants about each other's presence [45].

3.5 Other

Five studies did not completely fit into any of the three abovementioned categories. As a result, their characteristics are summarised separately in Table 4. These studies have contributed to the overall body of knowledge by using specific methods of investigation, for example by interviewing decision-makers, searching the media or evaluating the blind spots of existing trucks through using a vision projection technique.

The additional risk factors identified in these studies are difficult route planning to avoid interactions with cyclists [18], lack of consideration of freight planning within urban planning [40], lack of ownership (and awareness) of road risk by clients and contractors in the construction industry [18] and that road risk is seen as less important than general health and safety risks in the construction industry [18].

3.6 Recommendations for future research

The reviewed studies identified numerous recommendations for future research, which may be categorised into four groups - the impact of measures to improve drivers' indirect vision (1), trucks' design to improve direct vision (2), behavioural aspects (3) and evaluation of safety measures (4).

3.6.1 The impact of measures to improve drivers' indirect vision

The development and application of various measures aiming to improve drivers' indirect vision put increased demands on their users (particularly truck drivers). It is still not obvious what strategies are used by truck drivers to establish situational awareness of road users' location in close proximity to their truck, what is the actual task time and what are the mirror use strategies [61]. In addition, the interaction between certain cognitive truck drivers' tasks and reliance on their indirect vision to detect cyclists has not been examined [38]. The ergonomic, occupational, physiological and psychological effects of information and assistance systems on the drivers should be further explored as well [23, 30]. An investigation of annoyance levels among drivers caused by too many alarms/alerts associated with the vehicle systems is needed, as it affects the vehicle systems' efficiency levels [47]. Alternative interfaces (e.g. vocal or visual display alert) present another field for further research [47].

3.6.2 Trucks' design to improve direct vision

The truck's design determines the driver's direct vision; therefore, the variability of design features which contribute to the size of blind spots should be examined [61]. The components of optimum cab design should be defined in particular, [38] and the direct vision standards for use by vehicle manufacturers developed [55]. The new design concepts require the development of training procedures for drivers to obtain expert driving skills when driving the latest cab designs [38].

3.6.3 Behavioural aspects

Aspects of frequent misunderstanding in truck driver-cyclist interactions require further examination [30]. For example, cyclists' decision-making skills when encountering trucks; the effects of different levels of cyclists' salience on direct and indirect visibility [38], and the effects of

Table 3 Characteristics of safety measure studies

Study	Aim	Method	Measure	Type of measure	Type of truck
Fenn et al., 2005 [24]	Assess the casualty reduction potential through compulsory fitting of close proximity blind spot mirrors to HGV	Literature review, accident analysis, vehicle analysis, surveys	Compulsory fitting - Blind spot mirrors	Legislation - Vehicle equipment	All types of HGV
Niewoehner & Berg, 2005 [23]	Investigations into the field of view	Field tests	Mirrors, Fresnel lens	Vehicle equipment - active	Goods vehicles over 3.5 t
Knight et al., 2006 [42]	Investigate the benefits of adopting an integrated approach to several measures	Literature review, computer simulation, spray measurement, cost-benefit calculation	Sideguards, front and rear underrun protection, spray suppression	Legislation - Vehicle equipment	HGV
Feist et al., 2008 [43]	Evaluate several concepts	Conceptual analysis, simulation, expert panel discussion	Energy-absorbing front end	Vehicle equipment - passive	HGV
Ahrholdt et al., 2009 [44]	Development of traffic safety application	Field test	Combined perception system	Vehicle + infrastructure equipment - active	HGV (rigid truck)
FDS International (2010) [34].	Evaluate behaviour related to roadside mirrors	Survey	Roadside mirror	Infrastructure equipment	LGV (long heavy vehicles)
Cookson & Knight, 2010 [25]	Inform consideration of the effectiveness of sideguards on HGV to pedal cycle accidents	Literature review, before-after comparison, accident analysis	Sideguards	Vehicle equipment - passive	HGV
Lausnay et al., 2011 [45]	To develop and test a means of detecting cyclists	Static and dynamic test	Wireless communication system	Vehicle equipment - active	Truck
Lakshminarayana et al., 2011 [46]	Investigation of bicyclist kinematics during side and rear-end collisions	Simulation	Energy absorbing frontal system	Vehicle equipment - passive	HCV (Heavy Commercial Vehicle, 16 t)
Twisk et al., 2013 [37]	Evaluate awareness programs	Experiment	Awareness program for adolescent cyclists	Education	Lorry
Thompson et al., 2013 [47]	Develop and test a system using in-vehicle three-dimensional (3D) sound as a technique for augmenting truck drivers' situational awareness	Experiment, field test	3D sound	Vehicle equipment - active	Truck
Rechnitzer & Grzebieta, 2014 [48]	Estimate the effects of side underrun protection	Summarizes the types of side-underrun systems used in Europe and Asia, Expert estimation	Side underrun protection	Legislation – vehicle equipment	Truck
Robinson & Cuerden, 2014 [49]	Estimates the probable effect of removing exemptions and achieving full retrofitting compliance in London	Prediction	Retrofitting - Side guards and mirror	Legislation - vehicle equipment	Medium (3.5–7.5 t) and Heavy (over 7.5 t) Goods Vehicles
Beeck & Goedeme, 2015 [50]	Develop an active safety system based solely on the vision input of the blind spot camera	Experiment	Detection and tracking framework	Vehicle equipment - active	Truck
Miah et al., 2015 [51]	Evaluate and validate sensor accuracy	Calculation	Cyclist Alert System	Vehicle equipment - active	Heavy Vehicle

Table 3 Characteristics of safety measure studies *(Continued)*

Study	Aim	Method	Measure	Type of measure	Type of truck
Miah et al., 2015 [52]	Present a new concept	Experiment	Cyclist Alert System	Vehicle equipment - active	Heavy Vehicle
Islam et al., 2015 [53]	Propose the optimal controller (using particle swarm optimization technique)	Modelling	Optimal steering control	Vehicle equipment - active	A-double combination (semi-trailer)
Davis & White, 2015 [54]	Provide overview about means utilized	not relevant	Safety programme	Management	Construction vehicles
Summerskill & Marshall, 2015 [55]	Redesign truck concept and evaluate direct vision	Projection technique	Improved direct vision	Vehicle design	Different types of truck cabins
Pyykonen et al., 2015 [56]	Development of a monitoring system for assisting truck driver training	Field test	Training vehicle	Education	HGV
Jia and Cebon, 2016 [57]	Build a prototype system and test it in real time	Field test	Collision avoidance system - ultrasonic sensors on the truck	Vehicle equipment - active	Tipper truck
Seiniger et al., 2017 [58]	Provide knowledge for testing procedures of various driver assistance systems	Field test	Driver assistance system for blind spots	Vehicle equipment - active	Single tractor
Richter & Sachs, 2017 [32]	Evaluate driving and gaze behaviour using turn-off assistant, suggest infrastructure measures	Experiment	Turn-off assistant	Vehicle equipment - active	Van, delivery truck, truck without trailer, semitrailer truck
Martin et al., 2017 [59]	Evaluate cost-effectiveness of a range of clustered safety measures, identify regulatory options and future research needs	Review of technologies, systematic review of literature on safety measures, CBA calculations	Direct/indirect vision, impact protection, front underrun protection, VRU airbag	Legislation - Vehicle equipment/Design	HGV (N2 and N3 category)

Table 4 Characteristics of other studies

Study	Aim	Method	Truck definition
Gelino et al., 2012 [26]	Identify the safety challenges in Seattle and potential safety approaches	Literature review; review of current practices in other US cities; accident analysis; media search	Large trucks
Helman et al., 2013 [18]	Identifying features of contractual arrangements, working practices and vehicle design that contribute to collisions between construction trucks and cyclists	Literature review; Direct and indirect visibility assessment of construction vehicles; Semi-structured interviews with stakeholders	Construction vehicles
Pattinson and Warwick, 2014 [60]	Discuss several safety issues and measures	Overview, discussion	Trucks, Large vehicles
Summerskill et al., 2016 [61]	Evaluating blind spots of six top selling trucks in UK	CAD-based vision projection technique	Large Goods Vehicles (N2 and N3)
Pitera et al., 2017 [40]	Evaluate the decision-making process in implementing a risky layout of docking loading area for trucks	Interviews with decision makers	Delivery trucks

stationary or moving trucks on cyclists' risk perception in passing manoeuvres [35] present important research topics. Furthermore, the relationship between findings from behavioural studies and accidents' causation is lacking [17, 39].

3.6.4 Evaluation of safety measures

While there have been numerous studies completed on safety measures, cost-benefit and feasibility studies on these measures are lacking [33]. Safety evaluations require an examination of measures' safety implications before they are either deployed in vehicles or otherwise implemented [38]. It would be helpful to gain a deeper knowledge of pre-crash scenarios and better understand the potential impact of safety measures [27]. In the case of infrastructure measures reducing space capacity for truck traffic (e.g. caused by traffic calming), the short and long-term implications related to truck operations, costs, and externalities are often unknown [4].

4 Discussion

4.1 Methods and results

The methodologies identified in this scoping review may be categorized as accident analysis (i.e. police statistics, in-depth studies, forensic studies), non-accident analysis (i.e. conflict and behavioural studies) and safety measure evaluations (e.g. field tests, computer simulations, cost-benefit analysis, experiments). It is necessary to consider national/local conditions carefully when interpreting, comparing or transferring the results of these studies, as local/national differences in infrastructure (e.g. degree of segregation), legislation (e.g. compulsory truck safety equipment, cycling legally on sidewalks), enforcement (e.g. time and area restrictions on truck traffic), and/or land use (construction activities in residential areas) impact results. The different definitions of trucks used in the studies must be taken into consideration as well.

4.1.1 Accident analysis

The fact that trucks are overrepresented in fatal and severe bicycle accidents has been recognised as early as the 1980s and 90s (e.g. [13]); however, according to this review, studies related specifically to truck-bicycle safety concerns were not conducted until later,(beginning in 2003). There is strong consensus regarding the high level of severity and typical characteristics of truck-bicycle accidents (TCA) within the accident studies. Typically, accident data used in these studies are police records. As most TCA occur in urban environments, all the studies focus on urban areas. Moreover, TCA results occur infrequently in small sample sizes, even if long study periods are applied. For instance, if one considers cities in particular, even 10–15 years can be too short a period to collect enough data for meaningful analysis (e.g. in Seattle, USA,61 TCA were recorded over an 11-year period, and in Trondheim, Norway, 19 TCA were recorded over a 15-year period [26, 31]). These small sample sizes and long study periods limit the usage of statistical modelling; therefore, it is typically only descriptive statistics that are applied in accident studies. Furthermore, during long study periods, the external conditions may have changed (e.g. new legislation implemented, new trucks introduced), which is not reflected in the studies. Additionally, potential underreporting and insufficient or inconsistent accident data quality might decrease the reliability of accident studies. Another limitation is the lack of data on exposure (e.g. data on specific vehicle types involved in TCA).

The in-depth analysis of fatal accidents enables us to explore the detailed characteristics of TCA, particularly those related to accident causation and, consequently, complementary studies that use more general police accident data. Because of the high share of fatal TCA, in-depth studies are common in truck-bicycle safety analyses (8 of 14 accident studies in this review contain an in-depth analysis). When interpreting the results of in-depth studies, smaller sample sizes and longer study periods (e.g. a Norwegian study contained 13 fatal TCA gathered over a 10-year period [31]) must be taken into consideration. As the fatalities in TCA are almost always cyclists, the in-depth studies did not provide any data from cyclists' point of view.

There was one forensic study identified in this review; however, as it analysed just one specific TCA, this did not allow for any generalisation. These types of studies are able to reveal the medical details regarding the injuries the cyclists suffer when involved in TCA, as was shown in a UK study that looked at the consequences surrounding cyclists' severe and fatal accidents. According to this study, cyclists injured in TCA suffered severe injuries and death as a result of uncontrollable haemorrhages.[2] Having an awareness of this injury profile may aid prehospital management staff and expedite patients' transfer to trauma centre care [8].

4.1.2 Non-accident analysis

When evaluating safety, non-accident studies are an alternative method of accident analysis due to the fact that these studies evaluate either conflicts or behaviour.

Conflict studies use conflicts as surrogate safety indicators. Nonetheless, while the numbers of truck-bicycle conflicts are higher than accidents, they are not as frequent as, for example, car-bicycle conflicts. Therefore, conflict studies require relatively long observation periods to gather enough data, and the usage of modern technology is vital to processing the data (e.g. software for detecting road users in video recordings). Retrospective surveys present another method of gathering data on conflicts; however, this method suffers from several well-known limitations as well (e.g. recalling bias). It is challenging to generalise the results of conflict studies, as each of them analyse different locations, manoeuvres or situations (e.g. loading area, turning manoeuvre, driving with turn-off assistant). Furthermore, albeit all reviewed conflict studies have recognised the conflicts based on an evasive action, the threshold between evasive and normal action was identified subjectively without any quantification. This potentially contributes to the different conflict rates observed between studies - one study identified two conflicts during 100 h of observation, while the other one identified 71 conflicts in 129 h [30, 41].

The low number of conflicts combined with technical and methodological challenges connected with the data collection and evaluation highlight the need for behavioural studies. These can take the form of an observation (both in real traffic and a simulator) or a survey. Such types of studies are suitable for evaluation and testing of novel equipment (e.g. human-machine interface), studying perceived risk or observing the interactions between road users. Behavioural studies provide not only valuable insight into the behavioural aspects of truck-bicycle encounters but also have the potential to interpret the findings from accident analysis. For example, the overrepresentation of female cyclists was reported in several accident analyses [23, 30, 32]. The behavioural study conducted by Frings et al. reported that females perceive risk differently when making certain manoeuvres around trucks [35], while Abadi and Hurwitz determined through another behavioural study that females' perceived level of comfort differed substantially when bicycling in high-volume traffic or truck traffic [17]. At the same time, behavioural studies may highlight a phenomenon not seen in accident studies. For example, adult cyclists are the group most frequently involved in TCA [33], while a behavioural study found that young adolescent cyclists have difficulties in dealing with blind spot areas around trucks and could therefore be a suitable target group for receiving some kind of educational measures [37].

The validity of non-accident studies (i.e. whether unsafe behaviour or the presence of conflicts are an indicator of actual risk) presents another crucial issue when interpreting their results. There has not been any validation study conducted thus far to link truck-bicycle conflicts with accidents specifically. Moreover, this type of study is likely impossible to conduct due to the infrequency of relevant accidents.

However, as accidents are very rare, the shift towards behavioural studies can be expected, ones that not only focus on driver-machine interactions but also on driver-cyclist interactions. Furthermore, the recent development of autonomous vehicles highlights the need for behavioural studies, as they can gather knowledge of cyclists' behaviour when in proximity with trucks in different traffic situations and settings.

4.2 Risk factors

It is widely agreed that limited visibility (both direct and indirect) is the most serious risk factor for TCA. Nevertheless, a wider range of risk factors related to all components of the road transport system has been identified in this review. This list of risk factors is useful and informative when trying to understand truck-bicycle encounters; however, it does not allow for any quantification of risk factors' effects. As the data about exposure is usually unavailable, it is often impossible to estimate the risk factors' magnitude. A rare example of including exposure into the risk analysis may be found in a study from the UK, which concluded that rigid trucks (particularly ones related to the construction industry) are overrepresented in truck-bicycle accidents [18].

The risk factors identified by non-accident studies are typically more detailed and concrete than those from accident studies. For example, reduced visibility has been identified by accident studies as being the most frequent risk factor, while non-accident studies are able to go deeper and identify factors that may contribute to reduced visibility (e.g. slower drivers' reaction times to mirrors or cognitive overload). Furthermore, non-accident studies have the potential to reveal risks that are hidden within an accident analysis, e.g. the survey between involved stakeholders may reveal risk factors within the decision-making process [40]. Risk factors identified in the safety measures studies were risks directly related to the new measures implemented.

The identified risk factors predominantly focus on vehicles, road users or infrastructure. Given the complexity of transport system, risk factors existing in all its levels, including those related to the transport system management, urban and transport planning and legislation, should be analysed as well. If this analysis were to take place, it would, ideally speaking, consider their mutual interactions and influence.

4.3 Safety measures

Regarding safety measures, much of the current research focuses on improving direct and indirect visibility, which, as stated previously, has been identified as being the most severe risk factors in truck-bicycle safety. Specifically, there is an emphasis on active safety measures implemented in the trucks and issues related to the interactions of truck drivers with these novel measures. Passive safety measures, such as forgiving truck design, can also lessen the consequences of truck-bicycle accidents, but are paid less attention in the current literature specific to truck-bicycle accidents.

As risk factors exist in all levels of the road transport system, more systematic measures need to be studied as well because these measures could reduce the opportunities for trucks and bicycles to encounter one another in the first place. This could be done, for example, by infrastructure segregation (cycle paths), traffic management segregation (designated signal phases), network segregation (designated truck routes, access limitation), or time segregation (certain times for truck deliveries). The layout of sensitive locations (e.g. docking areas or construction sites) should be planned in cooperation with stakeholders from urban freight, transport and safety fields. Yet these solutions will only have an impact on the specific locations where they are implemented unless they are considered more comprehensively at the highest level of the road transport system and included within legislative and policy measures. Other policy measures to consider include ones related to retrofitting trucks or targeted education and training. Additionally, the potential impact of land use planning, traffic planning and urban logistics to generate/influence truck traffic must be considered.

Before implementing any efficient safety measures, they must first be evaluated. Future research should therefore provide further data for conducting evaluations, including a cost-benefit analysis of the proposed measures. So far, only a few cost-benefit studies have been conducted (particularly at the EU level) on the retrofitting of specific truck categories with blind spot mirrors or side guards [24, 25]. The effects of clustering the measures should be considered as well.

5 Conclusion

The increasing number of cyclists and trucks, and the severe consequences of their encounters, have increased interest in conducting truck-bicycle safety research and implementing knowledge-based safety measures. This study examines the existing literature on truck-bicycle safety within a scoping review. The review compiles the existing research on the topic and considers the methods used, risk factors identified, and future research needs. The reviewed literature falls under the categories of accident and non-accident (conflict and behaviour) studies as well as studies of safety measures. Accident and conflict studies examine past events in order to draw conclusions from dangerous encounters between trucks and bicycles; but as these events are rare, they may be complemented with behavioural studies aiming to understand how these road users behave during encounters. Several accident risk factors were identified from the studies. Within the current literature, these have generally focused on risks related to vehicles, road users and infrastructure. At the same time it has been suggested that there is a need to consider risk factors related to management, planning, and legislation as well. Having knowledge of risk factors contributes to implementing efficient safety measures, and studies of safety measures have also been identified in the review. These studies are useful for evaluating the impact of efforts to reduce risk and improve safety associated with truck-bicycle interactions. While existing studies have focused on direct and indirect visibility, there is also a need to consider system-level measures related to policy, planning, design and operations.

6 Endnotes

[1] Therefore, studies analysing cycle accidents with motor vehicles in general and concluding that trucks are frequently involved, have not been considered in this review.

[2] A massive leakage of blood caused by a ruptured blood vessel.

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PP conducted the literature search and prepared the draft of the manuscript. KP provided comments and language check. Both authors worked together on the preparation of the final version of the manuscript. Both authors read and approved the final manuscript.

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References

1. Pucher, J., & Buehler, R. (2017). Cycling towards a more sustainable transport future. *Transport Reviews, 37*(6), 1–6. https://doi.org/10.1080/01441647.2017.1340234.
2. Dablanc, L. (2007). Goods transport in large European cities: Difficult to organize, difficult to modernize. *Transportation Research Part A: Policy and Practice, 41*(3), 280–285. https://doi.org/10.1016/j.tra.2006.05.005.
3. Jaller, M., Holguín-Veras, J., & Hodge, S. (2013). Parking in the city: Challenges for freight traffic. *Transportation Research Record: Journal of Transportation Research Board, 2379*, 46–56. https://doi.org/10.3141/2379-06.
4. Conway, A., Tavernier, N., Leal-Tavares, V., Gharamani, N., Chauvet, L., Chiu, M., & Bing Yeap, X. (2016). Freight in a bicycle-friendly city. *Transportation Research Record: Journal of Transportation Research Board, 2547*, 91–101. https://doi.org/10.3141/2547-13.
5. Vandebulcke, G., Thomas, I., & Panis, L.I. (2014). Predicting cycling accident risk in Brussels: A spatial case-control approach. *Accid Anal Prev, 62*, 341–357. https://doi.org/10.1016/j.aap.2013.07.001.
6. Allen-Munley, C., & Daniel, J. (2006). Urban bicycle route safety rating model - application in Jersey City, New Jersey. *Journal of Transportation Engineering, 132*(6), 499–507. https://doi.org/10.1061/(ASCE)0733-947X(2006)132:6(499).
7. Kim, J.-K., Kim, S., Ulfarsson, G. F., & Porrello, L. (2007). Bicyclist injury severities in bicycle-motor vehicle accidents. *Accident Analysis & Prevention, 39*(2), 238–251. https://doi.org/10.1016/j.aap.2006.07.002.
8. Manson, J., Cooper, S., West, A., Foster, E., Cole, E., & Tai, N. R. M. (2012). Major trauma and urban cyclists: physiological status and injury profile. *Emergency Medicine Journal, 30*(1), 32–37. https://doi.org/10.1136/emermed-2011-200966.
9. Kaplan, S., Vavatsoulas, K., & Prato, C. G. (2014). Aggravating and mitigating factors associated with cyclist injury severity in Denmark. *Journal of Safety Research, 50*, 75–82. https://doi.org/10.1016/j.jsr.2014.03.012.
10. Chen, P., & Shen, Q. (2016). Built environment effects on cyclist injury severity in automobile-involved bicycle crashes. *Accident Analysis & Prevention, 86*, 239–246. https://doi.org/10.1016/j.aap.2015.11.002.
11. Ackery, A. D., Mclellan, B. A., & Redelmeier, D. A. (2012). Bicyclist deaths and striking vehicles in the USA. *Injury Prevention, 18*, 22–26. https://doi.org/10.1136/injuryprev-2011-040066.
12. OECD/International Transport Forum. (2013). *Cycling, health and safety, OECD. Publishing/ITF*. https://doi.org/10.1787/9789282105955-enOECD.
13. McCarthy, M., & Gilbert, K. (1996). Cyclist road deaths in London 1985–1992: Drivers, vehicles, manoeuvres and injuries. *Accident Analysis & Prevention, 28*(2), 275–279. https://doi.org/10.1016/0001-4575(95)00061-5.
14. Morgan, A. S., Dale, H. B., Lee, W. E., & Edwards, P. J. (2010). Deaths of cyclists in London: Trends from 1992 to 2006. *BMC Public Health, 10*(669), 1–5. https://doi.org/10.1186/1471-2458-10-699.
15. Aldred, R., & Crosweller, S. (2015). Investigating the rates and impacts of near misses and related incidents among UK cyclists. *Journal of Transport & Health, 2*(3), 379–393. https://doi.org/10.1016/j.jth.2015.05.006.
16. Sanders, R. L. (2015). Perceived traffic risk for cyclists: The impact of near miss and collision experiences. *Accident Analysis & Prevention, 75*, 26–34. https://doi.org/10.1016/j.aap.2014.11.004.
17. Abadi, M. G., & Hurwitz, D. S. (2018). Bicyclist's perceived level of comfort in dense urban environments: How do ambient traffic, engineering treatments, and bicyclist characteristics relate? *Sustainable Cities and Society, 40*, 101–109. https://doi.org/10.1016/j.scs.2018.04.003.
18. Helman, S., Delmonte, E., & Stannard, J. (2013). *Construction logistics and cyclist safety*. Published project report PPR640. London: Transport Research Laboratory.
19. Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616.
20. Adams, R. J., Smart, P., & Huuf, A. S. (2017). Shades of grey: Guidelines for working with the grey literature in systematic reviews for management and organizational studies. *International Journal of Management Reviews, 19*, 432–454. https://doi.org/10.1111/ijmr.12102.
21. Mahood, Q., Van Eerd, D., & Irvin, E. (2014). Searching for grey literature for systematic reviews: Challenges and benefits. *Research Synthesis Methods, 5*(3). https://doi.org/10.1002/jrsm.1106.
22. Klintschar, M., Darok, M., & Roll, P. (2003). Fatal truck-bicycle accident involving dragging for 45 km. *International Journal of Legal Medicine, 117*(4), 226–228. https://doi.org/10.1007/s00414-003-0364-9.
23. Niewoehner, W., and Berg, A.F. (2005). Endangerment of Pedestrians and Bicyclists at Intersections by Right Turning Trucks. In Proceedings: 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington DC.
24. Fenn, B., Dodd, M., Smith, L., McCarthy, M., & Couper, G. (2005). *Potential casualty savings from fitting blind spot mirrors to HGV - final report*. London: TRL Limited.
25. Cookson, R., & Knight, I. (2010). *Sideguards on heavy goods vehicles: assessing the effects on pedal cyclists injured by trucks overtaking or turning lef.* Published Project Report PPR514. London: TRL.
26. Gelino, K., Krass, C., Olds, J., & Sandercock, M. (2012). *Why can't we be friends? Reducing conflicts between bicycles and trucks*. Seattle: University of Washington.
27. Johannsen, H., Jänsch, M., Otte, D., & Urban, M. (2015). Accidents involving turning trucks and bicyclists – Options for analysing countermeasures. In *Paper presented at international cycling safety conference 2015, Hannover, Germany.*
28. Seiniger, P., Gail, J., & Schreck, B. (2015). Development of a test procedure for driver assist systems addressing accidents between right turning trucks and straight driving cyclists. In *Paper presented at the 24th international technical conference on the Enhanced Safety of Vehicles (ESV), Gothenburg, Sweden.*
29. Britton, D. (2016). *Pedestrian and bicyclist fatalities in large truck crashes*. U.S. Department of Transportation , FMCSA, Washington. Retrived from https://rosap.ntl.bts.gov/view/dot/30820.
30. Malczyk, A., & Bende, J. (2017). Crashes between heavy vehicles and bicyclists: Characteristics, injury patterns and potentials for driverassistance systems. In *Paper presented at IRCOBI conference 2017, Antwerp, Belgium*.
31. Pokorny, P., Drescher, J., Pitera, K., & Jonsson, T. (2017). Accidents between freight vehicles and bicycles, with a focus on urban areas. *Transportation Research Procedia, 25*, 999–1007. https://doi.org/10.1016/j.trpro.2017.05.474.
32. Richter, T., & Sachs, J. (2017). Turning accidents between cars and trucks and cyclists driving straight ahead. *Transportation Research Procedia, 25*, 1951–1959. https://doi.org/10.1016/j.trpro.2017.05.219.
33. Talbot, R., Reed, S., Christie, N., Barnes, J., & Thomas, P. (2017). Fatal and serious collisions involving pedal cyclists and trucks in London between 2007 and 2011. *Traffic Injury Prevention, 18*(6), 657–665. https://doi.org/10.1080/15389588.2017.1291938.
34. FDS International (2010). Trial of roadside safety mirrors for cycle visibility. Transport for London, report 10016.
35. Frings, D., Rose, A., & Ridley, A. M. (2012). Bicyclist fatalities involving heavy goods vehicles: Gender differences in risk perception, behavioral choices, and training. *Traffic Injury Prevention, 13*(5), 493–498. https://doi.org/10.1080/15389588.2012.664796.
36. Conway, A., Cheng, J., Peters, D., & Lownes, N. (2013). Characteristics of multimodal conflicts in urban on-street bicycle lanes. *Transportation Research Record: Journal of Transportation Research Board, 2387*(1), 93–101. https://doi.org/10.3141/2387-11.
37. Twisk, D., Vlakveld, W., Mesken, J., Shope, J. T., & Kok, G. (2013). Inexperience and risky decisions of young adolescents, as pedestrians and cyclists, in interactions with lorries, and the effects of competency versus awareness education. *Accident Analysis & Prevention, 55*, 219–225. https://doi.org/10.1016/j.aap.2013.02.038.
38. Milner, R., & Western-Williams, H. (2016). *Direct vision vs indirect vision: A study exploring the potential improvements to road safety through expanding the HGV cab field of vision*. London: Ove Arup & Partners Ltd.
39. Mole, C. D., & Wilkie, R. M. G. (2017). Looking forward to safer HGVs: The impact of mirrors on driver reaction times. *Accident Analysis & Prevention, 107*, 173–185. https://doi.org/10.1016/j.aap.2017.07.027.
40. Pitera, K., Pokorny, P., Kristensen, T., & Bjørgen, A. (2017). The complexity of planning for goods delivery in a shared urban space: a case study involving

cyclists and trucks. *European Transport Research Review, 9*(3). https://doi.org/10.1007/s12544-017-0262-8.
41. Pokorny, P., Pritchard, R., & Pitera, K. (2018). Conflicts between bikes and trucks in urban areas—A survey of Norwegian cyclists. *Case Studies on Transport Policy, 6*(1), 147–155. https://doi.org/10.1016/j.cstp.2017.11.010.
42. Knight, I., Dodd, M., Bowes, D., Donaldson, W., Smith, T., Neale, M., Grover, C., & Couper, G. (2006). *Intergated safety guards and spray suppression - final summary report*. London: TRL Limited.
43. Feist, F., Gugler, J., Giorda, A., Avalle, M., & Puppini, R. (2008). Improvements to the protection of vulnerable road users: Retrofittable, energy-absorbing front end for heavy goods vehicles. *International Journal of Crashworthiness, 13*(6), 609–627. https://doi.org/10.1080/13588260802412943.
44. Ahrholdt, M., Grubb, G., & Agardt, E. (2009). Intersection safety for heavy goods vehicles. Advanced microsystems for automotive applications 2009, ISBN 978-3-642- 00745-3.
45. De Lausnay, S., Standaert, T., & Stevens, N. (2011). Zigbee as a means to reduce the number of blind spot incidents of a truck. In *Paper presented at IEEE 22nd international symposium on personal, indoor and mobile radio communications, Toronto, Canada*.
46. Lakshminarayana, K., & Mitra, S. Trucks with different external frontal frames: Comparing vulnerable road user's injury severities using MADYMO. In *Paper presented at 3rd international conference on road safety and simulation, Indianapolis, USA*.
47. Thompson, D. D., Wadding, K., & Garmon, E. (2013). Increasing truck driver's awareness: Use of in-vehicle 3D sounds. Safety IDEA Project 19, Volvo Technology of America.
48. Rechnitzer, G., & Grzebieta, R. H. (2014). So you want to increase cycling on roads: Then we need side underrun barriers on all trucks. In *Paper presented at Australasian road safety research, policing & education conference, 2014, Melbourne, Australia*.
49. Robinson, T., & Cuerden, R. (2014). *Safer lorries in London: Identifying the casualties associated with side guard rails and mirror exemptions*. Published Project Report PPRR683. London: TRL.
50. Van Beeck, K., & Goedem, T. (2015). Efficient multiclass object detection: detecting pedestrians and bicyclists in a truck's blind spot camera. In *Paper presented at 3rd IAPR Asian conference on pattern recognition, Kualalumpur, Malaysia*.
51. Miah, S., Kaparias, I., & Liatsis, P. (2015). Cyclist 360° alert: Development and testing of a prototype instrumented bicycle model for the prevention of cyclist accidents. In *Paper presented at the 47th annual conference of the universities' transport study group, City University London, UK*.
52. Miah, S., Kaparias, I., & Liatsis, P. (2015). Evaluation of MEMS sensors accuracy for bicycle tracking and positioning. In *Paper presented at 22nd international conference on systems, signals and image processing, London, UK*.
53. Islam, M. M., Laine, L., & Jacobson, B. (2015). Improve safety by optimal steering control of a converter dolly using particle swarm optimization for low-speed maneuvers. In *Paper presented at IEEE 18th international conference on intelligent transportation systems, Las Palmas, Spain*.
54. Davis, G., & White, H. (2015). Reducing accidents between construction vehicles and cyclists. *Civil Engineering, 168*(3), 131–137.
55. Summerskill, S., & Marshall, R. (2015). The development of a truck concept to allow improved direct vision of vulnerable road users by drivers. *Procedia Manufacturing, 3*, 3717–3724. https://doi.org/10.1016/j.promfg.2015.07.803.
56. Pyykonen, P., Virtanen, A., & Kyytinen, A. Developing intelligent blind spot detection system for heavy goods vehicles. *IEEE Transactions on Vehicular Technology*, 293–298.
57. Jia, Y., & Cebon, D. (2016). Field testing of a cyclist collision avoidance system for heavy goods vehicles. *IEEE Transactions on Vehicular Technology, 65*(6), 4359–4367.
58. Seiniger, P., Gail, J., & Schreck, B. (2017). A draft regulation for driver assist systems addressing truck-cyclist blind spot accidents. In *Paper presented at 25th international technical conference on the Enhanced Safety of Vehicles (ESV), Detroit Michigan, US*.
59. Martin, P., Knight, I., Hunt, R., O'Connell, S., Cuerden, R., & McCarthy, M. (2017). *Study on enhanced truck front end design*. London: TRL.
60. Pattinson, W., & Thompson, R. G. (2014). Trucks and bikes: Sharing the roads. *Procedia - Social and Behavioral Sciences, 125*, 251–261. https://doi.org/10.1016/j.sbspro.2014.01.1471.
61. Summerskill, S., Marshall, R., Cook, S., Lenard, J., & Richardson, J. (2016). The use of volumetric projections in digital human modelling software for the identification of large goods vehicle blind spots. *Applied Ergonomics, 53*, 267–280. https://doi.org/10.1016/j.apergo.2015.10.013.

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