Commercial Vehicles and Vulnerable Road Users

Jean-Louis Comeau
Brian Monk
Paul Boase
Dominique Charlebois
Peter Burns
Transport Canada

Alan German
Road Safety Research

Abstract

Vulnerable road users, notably pedestrians and cyclists, are at particular risk of death and serious injury when subject to adverse interactions with heavy commercial vehicles. Such situations are primarily a problem in urban environments, and at intersections, where heavy vehicles undertake turning manoeuvres. A study of real-world collisions involving heavy vehicles and vulnerable road users was conducted to identify the major causal factors related to the occurrence of fatalities in such crashes and to determine a range of appropriate countermeasures. The results demonstrate that the problem is largely due to an inability of the drivers of heavy vehicles to note the presence of adjacent vulnerable road users, and pedestrians and cyclists not being fully aware of the intentions and trajectories of the heavy trucks. The study strongly suggests that, for heavy trucks and buses, two very effective measures would be improvements to on-board driver-assistance safety systems, and greater public awareness of the dangers posed by heavy vehicles operating in urban environments.

Résumé

Le risque de décès et de blessures graves est particulièrement élevé chez les usagers vulnérables de la route, notamment les piétons et les cyclistes, lors d'une interaction négative avec des véhicules commerciaux lourds. De telles interactions sont surtout problématiques en milieu urbain et aux intersections où les véhicules lourds effectuent des manœuvres de virage. Une étude sur les collisions réelles mettant en cause des véhicules lourds et des usagers vulnérables de la route a été réalisée pour identifier les principaux facteurs de causalité des décès lors de collisions, et de définir une série de mesures de prévention appropriées. Les résultats de cette étude démontrent que le problème est en grande partie attribuable à l'incapacité des conducteurs de véhicules lourds de remarquer la présence d'usagers vulnérables de la route à proximité, et au fait que les piétons et les cyclistes ne sont pas pleinement conscients des intentions et des trajectoires des véhicules lourds. Les résultats de

l'étude suggèrent fortement que, pour les véhicules lourds et les autobus, deux mesures très efficaces seraient d'améliorer les systèmes de sécurité/d'assistance à la conduite intégrés dans les véhicules et de favoriser une sensibilisation accrue du public aux dangers que présentent les véhicules lourds exploités en milieu urbain.

INTRODUCTION

Pedestrians, cyclists, and motorcyclists are classified as vulnerable road users precisely because they travel through the traffic environment largely unprotected by safety structures. While cyclists and motorcyclists typically use safety helmets, these provide only head protection, and are primarily designed for events in which a rider falls from their vehicle and impacts the roadway.

All vulnerable road users are especially susceptible to the potential for serious and even fatal injuries should they be involved in crashes with an automobile, truck or bus that are typically much larger and faster moving. Such vulnerability is particularly evident when heavy-duty vehicles are involved in collisions with pedestrians and cyclists. The current paper considers the nature of fatal crashes involving pedestrians and cyclists who have interacted with heavy trucks and buses.

Transport Canada maintains the National Collision Database (NCDB), a database containing information from all police-reported motor-vehicle collisions on public roads in Canada. Statistics extracted from NCDB show that, while fatalities have dropped substantially over the past several decades, there are still about 2000 individuals killed on the nation's roads each year. [1]

On average, over the period 2011-2015, vulnerable road users, including pedestrians, cyclists and motorcyclists, accounted for 29% of these casualties. In particular, 16% of fatalities occurred to pedestrians and 3% to cyclists.

Of the fatal collisions involving heavy-duty vehicles interacting with pedestrians and cyclists, 80% were collisions with pedestrians and 20% with cyclists. The fatally-injured pedestrians and cyclists ranged in age from 1 to 91 years. The largest group of pedestrians (43%) was over 60 years of age, while the largest group of cyclists (43%) was in the age range 18-39 years.

Most of these collisions occurred in urban environments (71%), in clear weather conditions (71%), during the hours of daylight (63%), and at an intersection (54%). The majority of the involved intersections (74%) had some form of traffic control (i.e. traffic lights, stop sign, or a pedestrian crossing).

Most of the vehicles involved were straight trucks (41%). Many other collisions involved tractor-trailer units (29%) and buses (20%). The most common vehicle manoeuvres were going straight ahead (35%), turning right (20%) and turning left (15%).

METHODOLOGY

In 2004, Judgements of Inquiry were issued by the British Columbia Coroners Service concerning two pedestrian fatalities involving commercial vehicles. Five similar pedestrian fatalities were referenced in the documentation. All seven pedestrian fatalities occurred in Vancouver between 2000 and 2003.

The recommendations to Transport Canada were that convex mirrors, providing a driver with a view directly in front of their vehicle, generally known as crossover mirrors, be required to be mounted on the front corners of commercial vehicles. The Coroners' inquiries provided the impetus for Transport Canada to undertake a comprehensive review of fatal collisions involving pedestrians and cyclists (VRU) interacting with heavy-duty vehicles (HDV), notably heavy trucks and buses.

In 2005, sampling of collisions was initiated for a pilot study into the causal factors of fatal collisions. Fatal crashes were identified at various sites across Canada over the period 2005-2009. All of these incidents were subjected to in-depth collision investigations by multi-disciplinary research teams funded by Transport Canada. As part of this general study, a number of fatal crashes involving VRU's interacting with HDV's were documented.

For many years, Transport Canada has maintained a Special Collision Investigation Programme in which cases of particular interest and/or concern with regard to vehicle safety have been researched. [2] For the purpose of the present study, in addition to the crashes noted above, a number of incidents involving VRU-HDV's were extracted from the Special Collision Investigation Programme.

As a result of the above-noted research efforts, Transport Canada has a database comprising 99 fatal and non-fatal VRU-HDV crashes that were sampled during the period from 2000 to 2015. Due to the use of different data sources over varying time periods, this represents a convenience rather than a systematic sample of criteria collisions.

For the purposes of the present paper, the dataset was restricted to 85 of the 99 available cases.

The vast majority (95%) of the incidents investigated involved fatalities and so non-fatal collisions were excluded from the analysis. Two additional cases involved construction vehicles (road graders) that have significantly different geometric, structural, and operating characteristics than conventional heavy-duty trucks and buses.

Other cases that were excluded involved suicides, cyclists abruptly falling from their bicycles into the path of moving vehicles, and a vehicle driver suffering a medical emergency. These cases were deemed as not relevant to the current analysis as none of the specific circumstances lend themselves to mitigation through the implementation of normal countermeasures that might be applied to influence road user behaviour or enhance the safety of motor vehicles.

RESULTS

The 85 cases selected contain a total of 91 vulnerable road users as some cases involved multiple VRU's. While there was at least one fatality to a VRU in each of the crashes studied, the actual number of VRU's who were fatally injured was 86 out of the total of 91 (95%).

There were 57 cases (67%) involving pedestrians, and 28 cases (33%) involving cyclists. Two pedestrians were using mobility scooters, and four cyclists were riding power-assisted bicycles. Five cases involved multiple pedestrians.

The VRU's ranged in age from 5-89 years and were comprised of 63 pedestrians and 28 cyclists. The majority of pedestrians (52%) were 60 years of age and older, while the largest age group for cyclists (36%) was 18-39 years.

The vast majority of collisions occurred during clear weather (93%) and in daylight conditions (84%). Only 16% of collisions took place when it was dark, with and without artificial lighting from streetlights.

Most crashes occurred either at urban intersections (74%), which were almost always controlled by stop signs or traffic lights, or at points along urban roadways (22%). Individual incidents occurred on a rural road, in a driveway, and in a parking lot.

As shown in Figure 1, the majority of pedestrian crashes (56%) occurred when pedestrians were crossing the road at a marked or unmarked crosswalk and had the right-of-way (ROW). Another 12% involved crossings in a marked or unmarked crosswalk without the right-of-way. A significant number of pedestrians (25%) were crossing a road mid-block or just outside of a crosswalk. The majority of all pedestrian collisions (68%) involved a vehicle initially stopped and subsequently either turning left, right or continuing straight ahead.

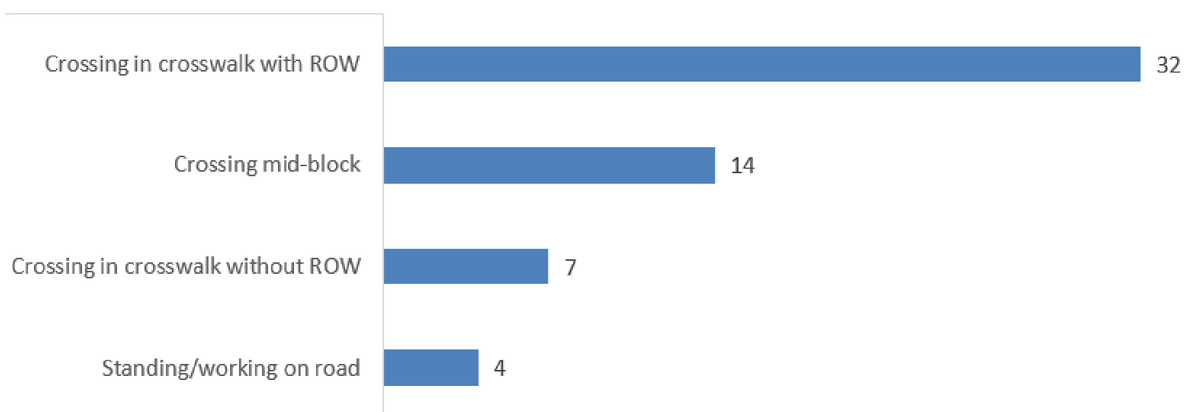

Figure 1. Pedestrian Action and Location (n=57)

Figure 2 shows that most collisions involving cyclists occurred when the cyclists were crossing an intersection either with or without the right of way (57%). The majority of cyclist collisions (75%) involved a right-turning vehicle that was either continuing in motion or starting from a stop.

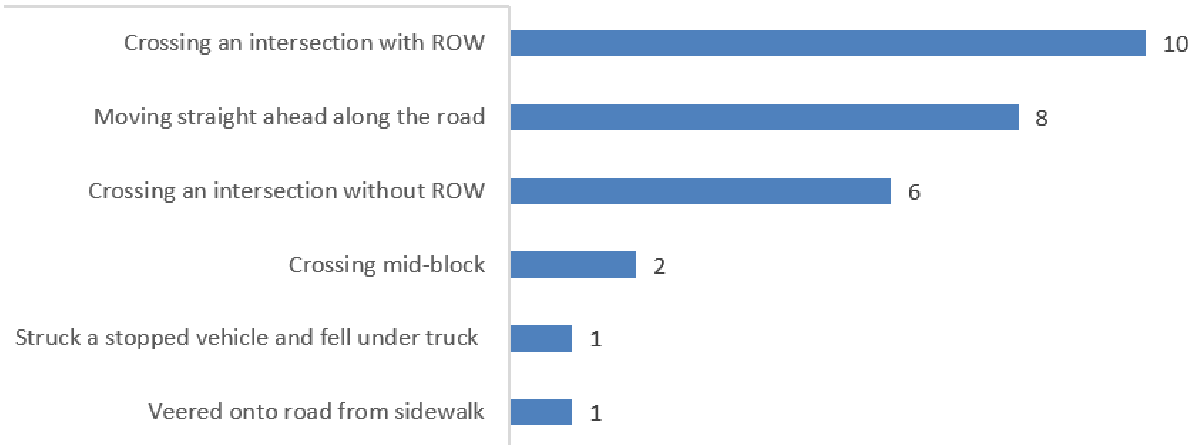

Figure 2. Cyclist Action and Location (n=28)

As shown in Figure 3, there was a wide variety of heavy commercial vehicles involved in the subject collisions and both conventional (71%) and cab-forward designs (29%) were represented. Figure 4 shows that the most common types of vehicles involved were dump trucks, with or without trailers, (27%), tractor-trailer combinations (19%), transit buses (15%), garbage/recycling trucks (13%), and straight box trucks (9%).

The VRU was run over by the commercial vehicle in 91% of the cases. The VRU was projected forward, and not run over, in 9% of the cases. The first point of contact with the VRU was the front surface of the vehicle in 55% of the cases, and a side surface of the vehicle in 38% of the cases. Of the cases involving the side structure of the vehicle, 91% involved the right side. Five incidents (6%) involved contact between the VRU and the rear of the vehicle.

CASE STUDIES

In a right-turning manoeuvre pedestrians or cyclists are often located on the vehicle's right side and thus largely outside of the driver's direct field of view. All of the heavy trucks and buses included in the current study were equipped with exterior, planar, rear-view mirrors on each side of the vehicle, as required by Canadian Motor Vehicle Safety Standard (CMVSS) 111. [3] However, additional mirrors were nearly always installed by the truck operators, or owners, to improve the driver’s field of view. Nevertheless, it should be noted that external mirrors often block a driver’s direct field of view and create blind spots. Other blind spots are present due to portions of the vehicle structure, notably the hood, roof-pillars, and any trailer.

Figure 3. Examples of Vehicle Types

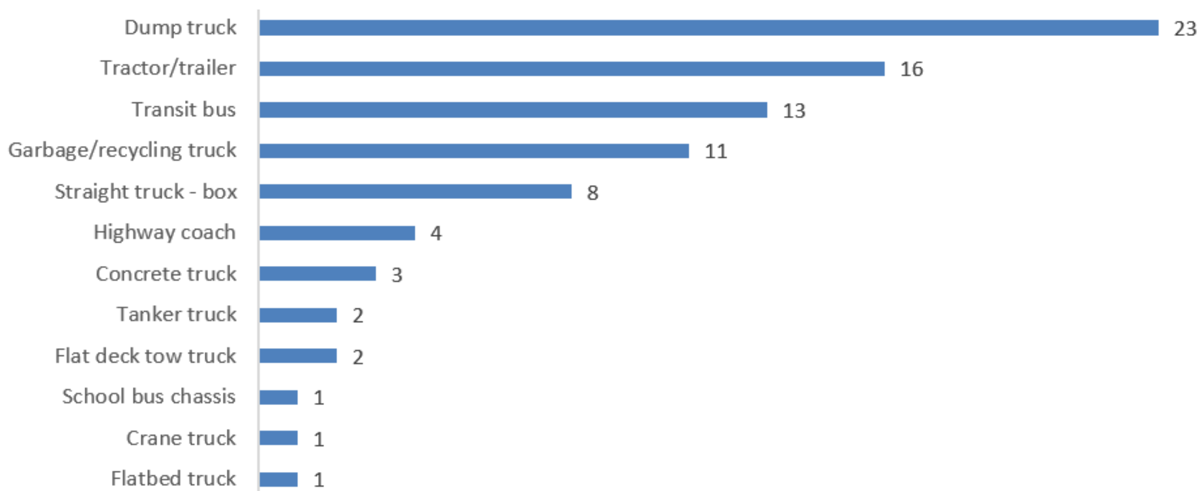

Figure 4. Vehicle Type (n=85)

As a large commercial vehicle progresses through a turn, the rear wheels of the vehicle track inside the path of the front wheels, creating the potential for the rear wheels to run over any adjacent VRU. None of the vehicles in the sample were equipped with side guards, however, a number of them had well-covered side structures between the front and rear axle(s), and many, such as highway coaches, had very low side ground clearances. These vehicle configurations, therefore, provided similar protective capability to that afforded by side guards.

An additional difficulty in providing protective structures on heavy commercial vehicles is the wide range of vehicle configurations and geometries. Even in jurisdictions where side guards are mandatory, there are usually many vehicle types that are exempt from the regulations since they are not compatible with the designs of conventional guards.

The above-noted hazards posed to vulnerable road users by heavy trucks and buses are exemplified by the following case studies.

Highway Coach – Pedestrian Collision

A 2008 Prevost X3-45, three-axle, highway coach (cab forward design) was travelling northbound along an urban road prior to making a right turn at an intersection. The speed limit was 40 km/h and the subject incident occurred on a clear summer evening in daylight. The bus was not carrying any passengers.

The bus was equipped with planar side-view mirrors with integrated smaller convex mirrors mounted to both front corners. The visibility zones, and the associated blind spots, for this configuration were mapped as shown in Figure 5.

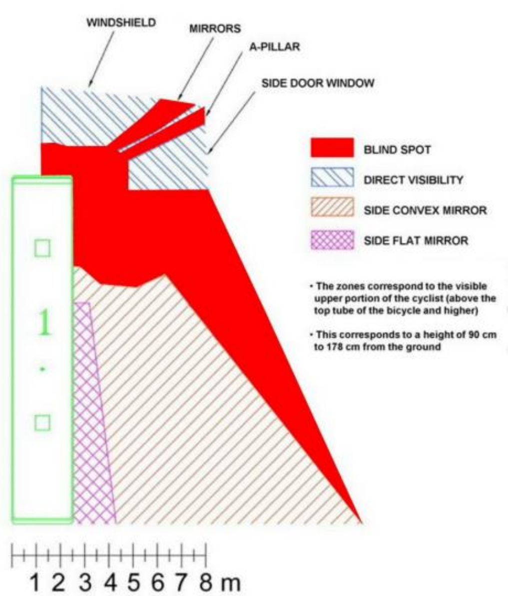

Figure 5: Field of View for 2008 Prevost X3-45 Highway Coach

The bus slowed to make the right turn onto the east/west road. At the same time, a teenage cyclist was travelling northbound along the sidewalk adjacent to the travel lane of the bus. The bus turned in front of the cyclist. The cyclist struck the side of the bus ahead of the rear axles, fell to the ground, was run over by the wheels on the two rear axles, and sustained fatal injuries.

The driver reported that he had not observed the cyclist on the sidewalk. It was noted that the bus had a side height from the ground, between the front and rear axles, of only 280 mm.

Dump Truck - Cyclist Collision

A 2007 Kenworth T800B dump truck, towing a Midland four-axle dump trailer, was eastbound along a designated truck route through an urban centre during daylight hours. A cyclist, using an eZee Liv electric bicycle, was also travelling eastbound along the right side of the road, ahead of the truck.

As the truck passed the cyclist, the rider, a 50-year-old male, moved to his left. He perhaps did not realize that the truck was towing the pup trailer by means of a 3.66 m long draw bar. The cyclist was struck by the trailer's first set of right-side wheels and was knocked to the ground. He was run over by the rear right-side wheels and sustained fatal chest and abdominal injuries.

Figure 6. 2007 Kenworth T800B Dump Truck and Pup Trailer

DISCUSSION

Given that the current analysis relates to a convenience sample of fatal collisions involving heavy trucks and buses interacting with pedestrians and cyclists, the data accord reasonably well with statistics extracted from recent years of the NCDB dataset. Furthermore, the current series of in-depth investigations highlight a number of common characteristics and some specific safety issues for this category of collisions.

The majority of collisions occurred in daylight at urban intersections during clear weather conditions and typically involved vehicles undertaking low-speed turning manoeuvres. A wide variety of truck types, with both cab-forward and conventional cab designs, was involved. The first point of contact was usually either the front or the right side of the vehicle. Every vehicle was equipped with mirrors systems that exceeded those required by CMVSS 111; however blind spots still existed.

The majority of collisions occurred within urban centres. The vulnerable road user was frequently located in, or near, a marked or unmarked crosswalk. The VRU was almost always run over and fatally injured. Drivers were not aware that their vehicle had struck a VRU until after the incident when they either noticed something unusual or were alerted by other road users. A number of VRU's displayed a lack of situational awareness and/or inattention.

A specific countermeasure that has been suggested is the installation of side guards on heavy commercial vehicles. In particular, this issue was raised in 2012 in the context of a review of pedestrian fatalities by Ontario's Chief Coroner. [4] This report indicated that half of the heavy truck-pedestrian fatalities involved the pedestrian coming into contact with the side of the truck, and subsequently being either pinned or run over by the rear wheels. A report produced by the National Research Council (NRC) indicated that, in the European Union, VRU deaths and serious injuries were reduced following the introduction of a side guard regulation for heavy vehicles. [5] However, the authors of this report were unable to ascertain if the observed trauma reductions were solely related to the presence of side guards or if these were just one contributing factor.

A wide-ranging review of the international literature on this subject has recently been completed by Epstein et al. [6] A total of 47 countries have regulations requiring side guards on commercial vehicles, and these devices are in widespread use in 65 countries. Japan has the most stringent ground clearance requirement of 450 mm while most jurisdictions allow 550 mm. However, the authors note that, in practice, side guard ground clearances tend to be in the range 380-400 mm.

As was noted earlier, one potential problem in implementing side guards on commercial vehicles is the wide array of vehicle configurations including the use of multiple axles, articulation points, and widely differing geometries in the structural components of these vehicles. Another of the confounding factors has also been highlighted by the circumstances of specific collisions in the present study where pedestrians ended up underneath heavy vehicles despite extremely low ground clearances of the vehicle side structures.

This has also been shown to be frequently the case in collisions involving cyclists. [7] It is clear, therefore, that low ground clearance, and closed-in sides on heavy trucks and buses, will not guarantee the safety of VRU's, especially in right-turn collision situations which pose the major hazard.

However, one of the possible advantages of side guard systems is that they do not require any behavioural changes on the part of commercial vehicle drivers. Some research and implementation efforts with respect to side guards are underway in Canada. The City of Edmonton has undertaken a pilot study that involves installing side guards on a number of garbage collection trucks, while the Lafarge company has undertaken to outfit its entire fleet of commercial vehicles with side-guard systems. [8]

In a study of fatal collisions between HDV's and cyclists, Cookson and Knight [9] concluded that improving the driver's vision to the side was one of the most effective individual vehicle-based countermeasures. The results of the present series of in-depth collision investigations also identified driver awareness of nearby pedestrians and cyclists as a significant issue. There are many competing demands for the driver’s attention when operating a commercial vehicle in a busy urban environment, so the addition of on-board driver-assistance technologies would be an extremely valuable resource. In particular, systems are needed to improve a driver's direct and indirect views around the vehicle's exterior, in combination with automatic detection systems that would alert the driver and adjacent VRU's to each other's presence.

To date, the primary means of enhancing the driver's view around the vehicle has been to provide supplementary mirror systems. However, the presence of mirrors themselves can result in blind spots, primarily by restricting the driver's direct view of areas outside of the cab.

Recent advances in electronic technologies, and in particular those related to digital imaging systems, may well provide a viable solution to such problems. Video cameras have been miniaturized, and their sensor systems refined in terms of their field of view and light-gathering ability. In particular, the cost of video cameras has been reduced considerably, and they are now being widely adapted for in-vehicle applications. [10] Rear-view cameras and in-dash display screens are being installed in many new light-duty vehicles. Similar camera systems may be embedded in a vehicle’s side mirrors. The relevant camera typically provides a wide-angle view that is projected on the monitor automatically when either reverse gear or the right-turn signal is engaged. On-board driver monitoring cameras are also being used to assess driver distraction and drowsiness. [11]

The underlying technologies have evolved so successfully that Working Party 29 (WP29) of the United Nations World Forum for Harmonization of Vehicle Regulations have amended UN Regulation No. 46 to permit all previously-mandatory mirrors for passenger cars, commercial vehicles, and buses to be replaced by camera-monitor systems (CMS). [12] Japan was one of the first jurisdictions to adopt these measures to allow domestic vehicles to use CMS instead of mirrors. [13] It is anticipated that more jurisdictions will follow suit, and such systems will become commonplace on all vehicle types at some point in the future.

Transport Canada is participating in a UN working group looking at requirements to enhance the driver's ability to detect vulnerable road users. [14] This group is developing requirements to improve a) the direct Field of Vision (FOV) of the vehicle driver, b) the detection of VRU’s with sensors and c) indirect vision, (e.g., camera systems).

It should be noted that a combination of forward-looking radar, digital cameras, and sophisticated image-processing systems are currently being used to detect the presence of objects, including pedestrians and cyclists, ahead of a vehicle's path of travel. [15] These systems can provide audible and visual warnings to the driver, and can automatically apply the vehicle's brakes in order to avoid, or at least mitigate, any collision.

Various camera-monitor systems are already being marketed for a range of applications in heavy trucks and buses. [16, 17] These systems offer a further means of reducing HDV-VRU casualties. The use of a comprehensive camera-monitor system provides drivers with access to multiple views around the entire vehicle and effectively eliminates blind spots. This is especially the case for cameras monitoring the sides of the vehicle during turning manoeuvres, and for backup cameras in reversing situations. In addition, it is likely that forward-facing cameras with image-recognition capabilities will be of assistance in situations where HDV's are travelling straight ahead, or when they are turning left, and VRU's are crossing the intersecting roadway directly ahead of the vehicle's intended path of travel.

For example, the Mobileye Shield Plus system [17] uses multiple cameras to detect pedestrians and cyclists, and constantly analyzes their movement with respect to the trajectory of the heavy vehicle. If a collision becomes a possibility, a signal is presented to the driver in the direction of the target, using a visual monitor installed on one of the vehicle's roof pillars. If the risk becomes more imminent, an audio alert will be generated to complement the visual alert, and the driver can take appropriate measures to avoid a collision. This process helps to limit distraction, while the active image sensors provide an extra set of eyes for the driver.

Figure 7: Mobileye Shield Plus System Installed on a Dump Truck

While camera-monitor systems clearly offer considerable potential for collision avoidance, care will need to be taken in implementing these devices in order to provide vehicle drivers with appropriate information without unduly affecting the driving task. Recent research studies have suggested a number of related concerns and possible solutions. [18, 19, 20]

CRASH AVOIDANCE RESEARCH

New crash avoidance technologies may help to address the risks to VRU’s that were identified in the real-world collision investigations. While many technologies currently available on the market can help limit the risk, it is important to fully understand the limitations of the technology. The mechanism provided to warn the driver needs to be as effective as possible to ensure that the imminent risk of collision is transmitted in time for the operator to take action. Half a second at 10 km/h has the potential to reduce the travelling distance by 1.4 m. This does not sound like much, but it can easily be the difference between avoiding a collision and a fatality.

Transport Canada is engaged in follow-on research to examine the potential benefits of sensors to detect vulnerable road users, and warn drivers when they are at risk near heavy vehicles. The first part of this project evaluated the test track performance of aftermarket sensor systems installed on a dump truck. Tests were performed on five different sensor systems:

1. Image recognition (vehicles and VRU's)
2. Image recognition (cyclist detection only)
3. 360 degree camera
4. Radar and camera (activated by turn signal)
5. Ultrasonic proximity sensors

Ten test track scenarios were developed based on the findings from the real-world collision investigations. These scenarios characterized a high risk, low speed, city environment. The manoeuvres included right turns, left turns, crossing in front of the large vehicle, as well as a combination of scenarios with moving VRU's. The dump truck travelled at either 20 km/h for crossing, or 10 km/h for turning. The three VRU test targets were 1) a 50th percentile adult male dummy, 2) a seven year old child and 3) an adult cyclist. All were propelled into the path of collision using a computer controlled towable platform.

Figure 8 – Test Vehicle with Crash Avoidance Sensors, Pedestrian and Cyclist Targets

A total of 250 tests were conducted to better understand the capabilities of the sensors designed to alert the driver of an imminent risk of collision. The image recognition technology performed best overall because it had fewer false positives and provided more time to react to the warnings.

In the second phase of this research, the best performing crash avoidance technology from the track tests was selected for extended field evaluations to determine how the systems perform under real world driving conditions. This field operational test (FOT) is currently underway using 14 large commercial vehicles, that typically operate in urban settings, and which have been equipped with smart camera technology. The year-long study is taking place in five Canadian cities and will be completed in the spring of 2019.

Data are being collected on the alerts issued to the driver, including the location, time of day, travel speed at the time of alert, and the system status. The focus is on measuring system performance under real-world operating conditions (e.g. weather, maintenance). Over the last eight months, the test vehicles have travelled over 225,000 km and there have been more than 6,000 VRU warnings. The performance of the crash avoidance technology ultimately depends on drivers' attitudes and acceptance of the systems. If drivers do not accept the system, they may ignore important warnings or turn the system off. So, crucial feedback is being collected from vehicle operators to evaluate the pros and cons of the technology on their workload (e.g. usage, workload, annoyance, false alarms, etc.)

A survey was designed to address the limitations of the system, and obtain an appreciation of how it operates around VRU's. The intent is to document how much the system is deemed useful or where it could be improved based on exposure and experience. Operators were given several weeks to become familiar with the system before being asked for comments. They were asked again after a few months to monitor if there were any changes in perception, or if new information about the system's operation emerged.

Two very important components that are difficult to assess are false positives and near misses. The system can monitor and document where VRU's are encountered and when they prompt an alert. Some metrics can help to understand if certain alerts are recurrent. For example, the truck may "see" a lot of VRU's at a busy intersection it frequently passes, but the proximity of the VRU's to the truck will determine the alert type and rate. It is possible to document how the system reacts and generates alerts, but it is very important in this study to understand how the operators are perceiving and using this information.

Efforts have been put in place to track and document the overall experience during the course of the year in order to understand if the operators are still noticing the alerts and using them to safely operate their vehicle. Exit interviews are also planned for the end of the pilot to complement the year-long accumulation of data.

CONCLUSIONS

A diverse range of countermeasures has been proposed to address the overall issue of vulnerable road user safety in Canada. [21, 22] The present study strongly suggests that, for heavy trucks and buses in particular, two very effective measures would be improvements to on-board driver-assistance safety systems, and the promotion of greater public awareness of the dangers posed by heavy vehicles operating in urban environments.

In recent years, dramatic improvements have taken place in safety systems based on electronic technologies that have been applied to light-duty motor vehicles. The use of these technologies needs to be quickly expanded to heavy trucks and buses in order to provide the drivers of these vehicles with enhanced capabilities to detect nearby vulnerable road users and also to alert these road users to the presence of the heavy vehicles.

In particular, camera-monitor systems could be used to replace and/or enhance side, crossover, and rear-view mirrors and provide drivers with more wide-ranging fields of view around their vehicle. The application of digital-signal processing and image-recognition technologies could then be integrated into these systems to automatically alert drivers to the presence of nearby pedestrians and cyclists.

In addition to providing alerts to the driver, integrated sensing and detection systems could be used to automatically implement collision-avoidance measures (e.g. pedestrian automatic emergency braking) where necessary, and/or provide warnings of the vehicle's presence to nearby road users. The same technology can also offer other safety features (e.g., forward collision warning and lane departure warnings).

The performance of the available sensor systems to detect VRU's and warn drivers is not yet guaranteed, so it remains incumbent on drivers to be cautious and vigilant when operating their vehicles around VRU's. The pedestrians and cyclists themselves should also be aware of their surroundings and any potential threats to their safety. Reinforcement of the dangers, especially in relation to trucks and buses making turns at urban intersections, and the on-going provision of recommended strategies to avoid conflicts in such situations, should be a continuing theme in traffic safety public education campaigns.

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The opinions expressed in this paper are solely those of the authors and do not necessarily represent the views and policies of Transport Canada.

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