TRUCK STRUCK REAR-END CRASHES: PROBLEM SCOPE AND AN AREA OF OPPORTUNITY

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Abstract

An opportunity exists to develop and implement smart safety technologies aimed at mitigating rear-end crashes involving heavy trucks—i.e., *truck struck* crashes. In the US, in 2018, there were 110,000 rear-end large truck crashes (National Highway Traffic Safety Administration, 2020). The truck struck crash scenario is not unique to the US, with recent data indicating that this crash scenario is also prominent in Malaysia, with a large number of Malaysian truck struck crashes involving motorcycles, which comprise a great percentage of the country's fleet. For truck struck mitigating technologies to be effective in a broad and diverse transportation ecosystem, these technologies will need to be "smart" enough to address motorcycle strikes. Previous research has been directed at addressing the truck struck crash scenario, and technologies to mitigate these crashes have been developed. However, before large-scale deployment can occur, longer-term testing of existing technologies is required along with further development to address the prevalence of motorcycles in truck struck scenarios.

Keywords: Truck crash, rear-end crash, truck struck, rear-lighting, truck safety, motorcycle safety

1. Introduction

In 2010, a research initiative was completed that developed a countermeasure to mitigate rear-end crashes with heavy trucks (Bowman et al., 2010). This countermeasure involved enhanced brake lights, mounted on the rear of the trailer, that would flash (pulse) to draw the following driver's attention to the forward roadway scene. The study was based on the hypothesis that following drivers are often distracted and, therefore, not focused on the forward roadway (Hanowski, 2011). Drawing a distracted driver's eyes to the forward roadway can prompt the driver to perceive and react to a slowing or stopped tractor trailer and avoid a crash.

Recently, one truck fleet in the US implemented a system, conceptually similar to that outlined in Bowman et al. (2010), on tanker trucks. Tanker trucks are ideal for this application, as the trailer is permanently attached to the tractor. For tractor-trailer configurations that do not have a "married" tractor and trailer, the rear signaling system may not remain with the tractor if its trailer is decoupled (e.g., hook-and-drop operations).

In their program, Bowman et al. (2010) developed both open loop and closed loop rear signaling systems. Open-loop systems activate simply with the tractor's deceleration and/or brake activation. Closed-loop systems include a detection component (e.g., lidar, radar), to detect following vehicles and calculate their time-to-collision (TTC). The lighting system is activated only for those vehicles with an unsafe TTC. Activation of the system in a closed-loop application is more sophisticated and tailored to the surrounding traffic.

The goal of this paper is to: (i) outline relevant US data, including the number of heavy/tanker trucks, motorcycles, and rear-end crashes, to provide the problem scope parameters of truck struck crashes, (ii) evaluate Malaysian data in a similar approach, (iii) describe Bowman et al.'s (2010) previously conducted work to develop a rear signaling system, and (iv) provide an overview of two research approaches that could be used to evaluate truck struck countermeasures prior to large-scale deployment. This project is a joint effort between researchers in the US and Malaysia with the common goal of reducing transport crashes.

1.1 US Data

According to a Federal Highway Administration's Highway statistics report, the US had over 13.2 million heavy trucks, 250.7 million light vehicles, and 8.6 million motorcycles registered in 2018 (2019). In the same year, vehicles in the US travelled a combined 3.2 trillion miles; 9% of these miles were driven by heavy trucks (Federal Motor Carrier Safety Administration [FMCSA], 2020). As of September 2020, over 2.15 million hazmat cargo tank trucks and over 2.13 million hazmat cargo tank trailers were registered in the Motor Carrier Management Information System (MCMIS).

The US Department of Transportation's National Highway Transportation Safety Administration (NHTSA) manages multiple unique crash databases. Records from all fatal crashes occurring in the US are stored in NHTSA's Fatality Analysis Reporting System (FARS) database, while sampled crashes from select US jurisdictions (crashes include property-damage only, injury, and fatal) are stored in the National Automotive Sampling System (NASS) General Estimates System (GES)/Crash Report Sampling System (CRSS). These databases were used to assess the impact of rear-end crashes of heavy trucks using five years of data from 2014 to 2018. During this period, fatal rear-end truck struck crashes totalled 2,032, resulting in 2,209 fatalities. The number of fatal rear-end crashes involving a heavy truck was at a five-year high of 453 in 2018 (Figure 1). In 2018, heavy trucks were 1.95 times more likely than light vehicles to be rear-ended in fatal crashes involving multiple vehicles. Over the period 2014 to 2018, heavy trucks were struck in rear-end crashes by approximately 311 motorcycles. In these crashes, 112 motorcyclist drivers or their passengers died. During this same time frame, the proportion of fatal rear-end truck struck crashes involving a motorcycle ranged between 4.5% in 2016 and 7.7% in 2014 (Figure 1).

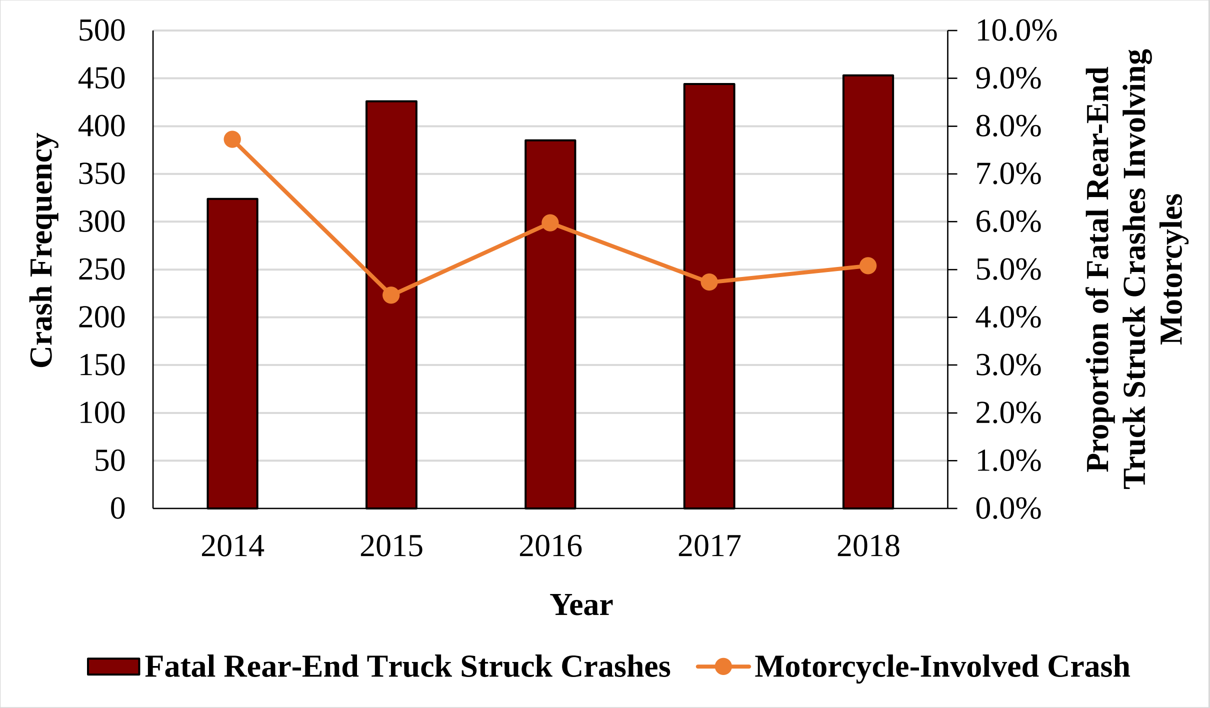

Figure 1. Fatal rear-end truck struck crashes of heavy trucks and the proportion of these crashes involving motorcycles (US data, 2014–2018).

The FARS/CRSS database includes detailed environmental and roadway descriptions for fatal crashes. Over the five-year period from 2014 through 2018, fatal rear-end truck struck crashes for heavy trucks most frequently occurred on two-way, divided highways (75.37%). Over 80% of these crashes occurred in speed limits of 55 MPH (89 KPH) or higher, and less than 1% of the crashes occurred at speed limits under 35 MPH (56 KPH). Fatal rear-end truck struck crashes in favourable dry road conditions resulted in 1,993 fatalities (an average of 1.08 fatalities per crash); in unfavourable road conditions, including wet, icy, snowy, slushy, or muddy roadways, these crashes resulted in 222 fatalities (an average of 1.12 fatalities per crash).

The striking vehicle was speeding in over 35% of fatal truck struck read-end crashes, including 201 crashes where the striking vehicle was exceeding the speed limit. In 2014, a quarter of fatal rear-end truck struck crashes involved a distracted driver in at least one of the crash-involved vehicles. This value was highest over the years 2014 through 2018, as shown in Figure 2. An average yearly percentage of 20.81% of crashes over the five-year period involved a distracted driver. Driver drinking in the striking vehicle was reported in 413 fatal truck struck crashes from 2014 through 2018. The yearly percentage of crashes involving driver drinking in the striking vehicle is shown in Figure 2 for the years 2014 through 2018.

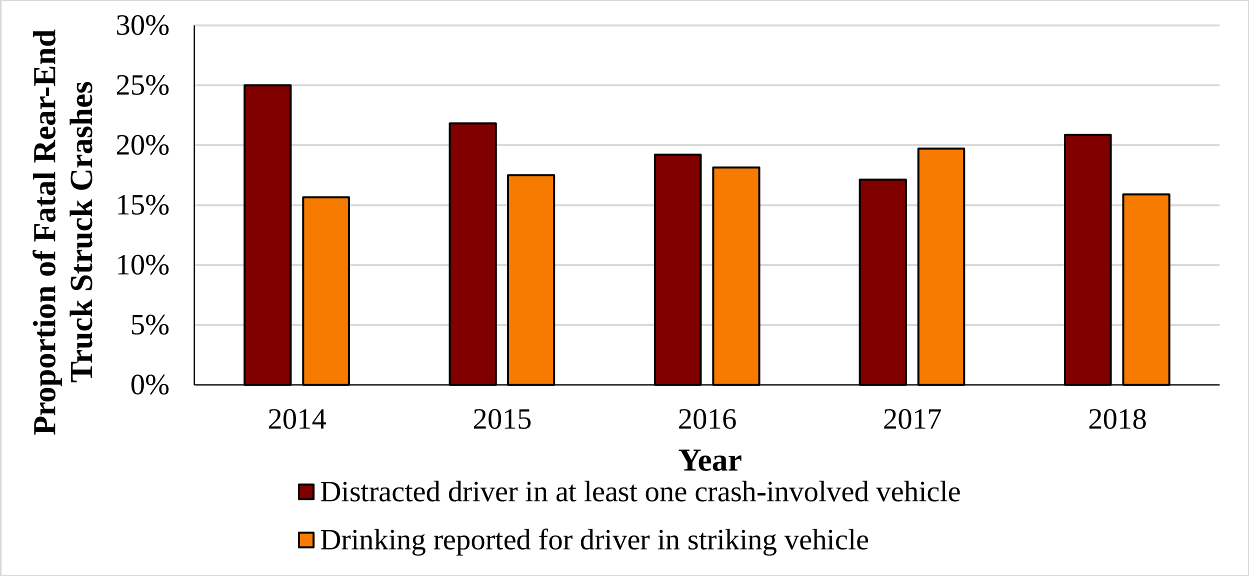

Figure 2. Proportions of fatal rear-end truck struck crashes of heavy trucks involving a distracted driver or drinking driver in striking vehicle (US data, 2014–2018).

1.2 Malaysian Data

According to the latest data, Malaysia has 1.26 million registered heavy trucks, which comprise 4.21% of the total vehicle fleet (Malaysian Road Safety Department, 2020). Drilling down further into these numbers, approximately 4.3% (or 53,821 units) of Malaysian-registered trucks are tankers. As of 2019, a total of 14,322,030 motorcycles were registered in Malaysia—an increase of 8.4% from the previous year (Malaysian Road Safety Department, 2020), making up 45.9% of Malaysia's 31.2 million vehicle fleet.

Fatalities involving motorcyclists are very high on Malaysian roads, despite that motorcycles account for only 12.3% of the total average annual vehicle kilometers traveled (Economic Research Institute for ASEAN and East Asia [ERIA], 2018). In 2018, road crashes resulted in 4,128 motorcycle fatalities (64.2% of total fatalities) in Malaysia (Abidin et al., 2018). MIROS Road Accident Database System (MROADS) was used to explore the prevalence of rear-end crashes involving heavy trucks in Malaysia. Five years of crash data from 2013 to 2017 indicate that rear-end crashes were the most common type of crashes involving heavy trucks in Malaysia, contributing to 30.1% of the total crashes (Malaysian Institute of Road Safety Research, 2020). Of all the rear-end crashes involving heavy trucks, motorcycle-truck rear-end crashes were the most prominent, contributing to 55.9% of the total number and resulting in 588 motorcycle fatalities. During the 2013–2017 period, 1,800 rear-end crashes were recorded, of which, 948 (52.7%) were rear-end truck struck crashes. The number of fatal rear-end truck struck crashes increased substantially from a five-year low of 24 crashes in 2013 to 273 crashes in 2016 (Figure 3). On average, motorcyclists contributed to more than a third of the yearly fatalities related to these types of crashes. The proportion of fatal rear-end truck struck crashes involving a motorcycle ranged from a five-year low of 26.6% in 2014 to a high of 46.2% in 2016 (Figure 3).

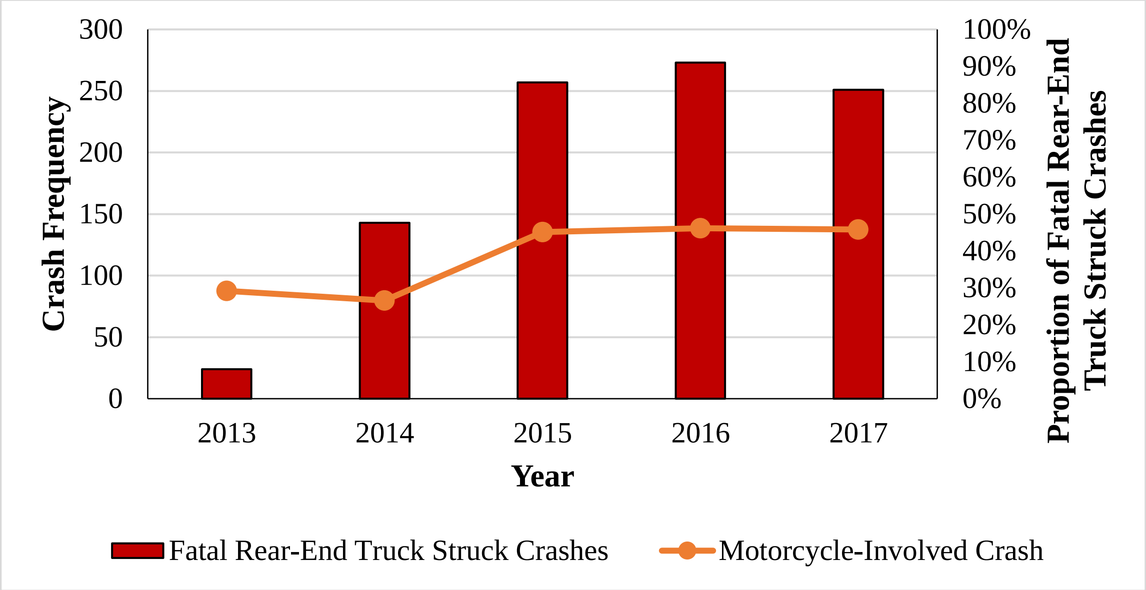

Figure 3. Fatal rear-end truck struck crashes of heavy trucks and the proportion of those crashes involving motorcycles (Malaysian data, 2013–2017).

The MROADS system was further explored to determine the detailed environmental and roadway descriptions for fatal crashes. In Malaysia, nearly half (49.3%) of all fatal rear-end truck struck crashes occurred on two-way, divided highways. More than half of these crashes (54.1%) occurred at speed limits of 55 MPH or higher, with only 6.6% of crashes occurring at speed limits under 35 MPH. From 2013 through 2017, fatal rear-end truck struck crashes in favorable dry road conditions resulted in 985 fatalities (an average of 1.06 fatalities per crash); in unfavorable road conditions, including wet or flooding roadways, these crashes resulted in 91 fatalities (an average of 1.20 fatalities per crash). Further, 56.8% of the fatal rear-end truck struck crashes occurred in daylight conditions and only 25.9% of these crashes occurred during the nighttime and without street light conditions.

Throughout the five-year period, only 39 drivers were found to be driving or riding under the influence of alcohol (1.3% of the total drivers involved). Unlike the US data, specific data was not available to investigate the influence of distracted driving for Malaysia. However, only 10 fatal cases were determined to be caused by careless driving, including driving too close to the vehicle in front. Speeding was not found to be the main cause of the fatal truck struck crashes in Malaysia. For all categories of truck-involved crashes, only two cases were found to be related to speeding during the five-year period. In terms of driver errors, the majority of drivers (of both the striking and the struck vehicles) involved in the fatal truck crashes in Malaysia were not found to be at fault during the crash investigation. Most of the crashes were characterized by a truck being struck from behind when stopping on the side of roads or in emergency lanes on highways, with a motorcycle being the most frequent striking vehicle. Based on the police investigation and description of the crashes, fatal truck struck crashes in Malaysia can be generally characterized as being caused by a failure to detect and evade a stopping or slow-moving truck.

To summarize the US and Malaysian data, rear-end crashes with heavy trucks appear to be a growing crash type. Recall that in the US, truck struck crashes that resulted in a fatality were at a five-year high in 2018 (the most recent data available). Similarly, in Malaysia, truck struck crashes accounted for 30.1% of total crashes. Furthermore, in Malaysia, considering all the rear-end crashes involving heavy trucks, motorcycle-truck rear-end crashes were the most prominent, accounting for 55.9% all such crashes. Over a four-year period in the US, between 2014 and 2018, 112 motorcyclists or their passengers died in truck struck crashes. Comparatively, in Malaysia, between 2013-2017, 588 motorcyclists died in truck struck crashes. The fatality numbers due to truck struck crashes is disproportionate when comparing US and Malaysian data. The main contributing factor to this increase appears to be the dominance of motorcycles in the Malaysian traffic network. Given the size differential between trucks and motorcycles, the end result of such crashes often leads to the death of the motorcycle rider(s). The large percentage of motorcycles within the Malaysian traffic network (and other ASEAN countries) indicates that, for truck struck crash countermeasures to be optimally effective, design consideration for the motorcycle rider is critical.

2. Previous Research for Countermeasure Development

Between 2005 and 2013, the FMCSA sponsored a series of projects to develop a rear-signaling system to mitigate truck struck crashes. Detailed in a technical report (Schaudt et al., 2014), and summarized in a journal paper (Bowman et al., 2010), the purpose of the rear signaling system was to alert drivers following large trucks of the trucks' deceleration. Figure 4 shows an example of one of the testing lighting configurations that was positioned on the back of the trailer. Results indicated that a "ganged" lighting approach worked best to draw the eyes of the following vehicle to the slowing tractor-trailer (TT). The project team developed both open-loop and closed-loop systems. In the open-loop system, the rear-signaling system would flash (i.e., pulse) whenever the truck decelerated at a pre-set threshold. In the more sophisticated closed-loop system, the rear-signaling system would only flash when there was a following vehicle approaching at a pre-set time-to-collision (TTC) threshold. As shown in Figure , the closed loop system utilized a radar system to detect and calculate the closing rate (velocity) and closing distance to the TTC and would activate the system when a rear striking crash was likely, as based on an adjustable TTC threshold.

Figure 4. Left, rear-lighting configuration developed and tested in Bowman et al. (2010). Right, radar to detect following vehicle TTC and initiate the flashing alert when a pre-determined threshold has been breached (Schaudt et al., 2010).

Data collection in the project included both static and dynamic testing. A key result was that following drivers' "Time to Look-up" (from a distracted condition) improved as a function of system use, suggesting the system was effective in drawing attention to the stopping lead truck (Schaudt et al., 2010). A lesson-learned from the study was that, due to logistical issues with the tractor-trailer configuration, the target truck configuration was optimal for those trailers that were "married" (i.e., permanently affixed) to the tractor. As the lighting system was attached to the trailer, a hook-and-drop trailer operation would separate the rear lighting system from the tractor as previously discussed. As such, until (or if) such technology becomes standard on trailers, these alerting system will be most likely utilized by fleet operations that maintain a consistent tractor-trailer combination.

Though it took approximately 10 years, and required an exemption from FMCSA, Groendyke Transport was the first known commercial carrier in the US to implement a seemingly functionally similar technology to that developed by Schaudt et al. (2010) for the purpose of mitigating truck struck crashes. As outlined by Park (2020), the system involved a flashing amber rear light that was activated when the truck driver applied the brakes. The system implemented by Groendyke was an open-loop system and provided alerts whenever the driver applied the brakes, regardless of whether or not a following vehicle was present. Groendyke Transport uses tankers for these systems, which underscores the notion that permanently coupled tractor trailers may be best suited for truck rear-signaling safety systems.

3. Rear-Signaling Effectiveness Evaluation Approaches

Conceptually, though trailer-mounted systems aimed at alerting following vehicles to TT braking seem reasonable, testing in a real-world setting would be an important design step before the large-scale deployment of such systems. To this end, two research approaches to assess the effectiveness of a TT rear-signaling system are summarily presented. The first approach is directed at an open-loop system, while the second approach is directed at a closed-loop system.

3.1 Approach 1: A Field Operational Test (FOT) to assess the efficacy of an open-loop system

This option includes a naturalistic driving study involving one or more fleets. Half of the participating TTs would be equipped with a fully operational open-loop system, while the other half of the participating TTs would be equipped with a *passive* system that does not activate, but, like the fully operational TT system, records following vehicle behaviours (e.g., speed, following distance) and driver behaviours (e.g., distraction of the following driver). Data could be collected for a 12-month period. All TTs would be instrumented with data collection equipment, including rear-facing video cameras and radar, GPS, and accelerometers on the TTs. These cameras and sensors would record whenever the truck was in motion, allowing for analysis of both safety critical events and general car following behaviours. This approach would use a random controlled design where half of the participants are randomly assigned to a baseline group (passive systems) and the other half to the intervention group (active systems). Key characteristics (e.g., experience, routes) of the truck drivers would be similar in both the passive and intervention groups. This research design would allow researchers to evaluate behavioural changes of the following-vehicle driver in response to the active system. Additionally, this approach allows for the evaluation of safety benefits, beyond behavioural changes, by comparing the rate of safety critical events between the baseline and intervention groups.

3.2 Approach 2: Comprehensive Engineer Study and FOT to assess efficacy of closed-loop system

The purpose of this approach is to develop an improved closed-loop system by addressing the engineering limitations in the system developed and tested in Schaudt et al. (2010). Following an engineering evaluation and improvements, system efficacy could be evaluated in a full-scale FOT. In brief, an engineering study would be completed to expand the rear signalling system to include night-time rear-warning light testing, radar firmware refinement, and final unit development and packaging.

Following the engineering study, a full-scale FOT would be performed to answer 18 research questions under operational conditions (detailed in Schaudt et al., 2010) regarding activation, sub-system performance, and following-vehicle driver behaviour. Based on the power analysis performed in Schaudt et al. (2010), this approach would use 32 trucks for data collection. Each truck would have a trailer (e.g., refrigerator van or tanker) that would remain permanently coupled over the course of a 12-month data-collection interval. Each of the 32 truck/trailers would be equipped with an enhanced rear signalling system and data collection equipment, including rear-facing video cameras and radar, GPS, and accelerometers. Of the 32 trucks, 24 would collect a four-month baseline data period and an eight-month test condition data period. The final eight instrumented trucks would serve as a control test. These controls would mirror the operations of the 24 experimental trucks while collecting baseline data throughout the entire 12-month period. The purpose of these controls would be to provide a comparison for uncontrolled circumstances, such as traffic, weather, and time of year. This FOT would result in an understanding of the efficacy of the closed-loop system by investigating the sub-system activation performance, following-vehicle driver behaviour, and safety benefits.

Of course, other research test approaches could be considered and conducted in addition to the two approaches highlighted here. However, to fully understand the benefits and potential unintended consequences of these systems, real-world fleet testing would be important prior to large-scale deployment.

4. Conclusion

Truck struck crashes, where a vehicle rams into the back of a tractor trailer, often result in the death of the following vehicle’s occupant(s). Because of the vulnerability of a motorcycle rider, truck struck crashes are particularly dangerous, and are nearly certain to end the life of the motorcycle rider(s). Data to support this is found in both the US and Malaysian data. In the US, between 2014 and 2018, 112 motorcycle rider deaths occurred in an estimated 311 recorded truck struck motorcycle-involved crashes. Put another way, based on those numbers, a motorcycle rider involved in a truck struck crash has approximately a 36% chance of dying. Such a severe critical crash outcome becomes more concerning when considering that the data shows a 71% increase in truck struck crashes between 2017 and 2018. Assuming this trend continues, truck struck crash fatalities are also likely to increase in the coming years.

Unfortunately, research findings are often only considered at local level, which can miss broader global implications and benefits. Applying a globalized approach to transportation safety research and research-based solutions could prove to be highly effective across diverse driving environments. The analysis presented herein is a clear example of that. Though 112 truck struck deaths may seem minor given the large number of roadway deaths each year in the US (approximately 40,000), this crash configuration could play out much differently in an area of the world where motorcycles are the dominant mode of transportation and frequently interact with large trucks. Malaysia is a good example of such an environment, where motorcycles comprised 45.9% of the Malaysian fleet in 2020, a percentage that is expected to continue increasing annually.

As would be expected given their predominance the fleet, motorcycle fatalities are high in Malaysia, accounting for 64.2% of all roadway fatalities in 2018. In terms of the most prominent following vehicle type in truck struck crashes in Malaysia, motorcycles take the top spot, accounting for 55.9% of all truck struck crashes between 2013 and 2017. As outlined by the Federal Highway Administration (2015), motorcycle ridership nearly doubled in the US, from 4.3 million in 2000 to 8.4 million in 2014. As in the US, Malaysia is seeing an increase in motorcycle ridership, with an 8.4% annual increase from 2018 to 2019. Considering data from both countries, the consistency of truck struck crashes having severe, often deadly, outcomes, and the increasing frequency of such occurrences should ring alarm bells with riders, transportation officials, safety advocates, and policy makers, particularly in parts of the world where motorcycles are the predominant mode of transportation.

The frequency and severity of truck struck crashes revealed in the US and Malaysian data present an opportunity to develop and implement smart safety technologies aimed at mitigating this crash type. Research has been conducted on such systems (Bowman et al., 2010) and small deployments have occurred in the US (Park, 2020) with positive findings of reduced truck struck crashes. Additional research may be required to further refine the system to be sufficiently sensitive to various vehicle configurations. For example, the data presented in this paper makes the case for truck struck countermeasures to include sensitivity (i.e., identification and alerts) to motorcycles. Though deployment of promising safety technologies in a landscape of an increasing problem scope should be acted upon with vigour, field testing and evaluations of such systems should be included in the roll out program. Following such a strategy, efficacy of these systems can be better understood and refinements, if needed, made easier to address.

Truck struck crashes have not been well studied and additional research is likely required. Nonetheless, enough is known to understand that truck struck crashes represent an increasing issue that is particularly catastrophic to operators of vulnerable vehicle types, particularly motorcycles. There is a clear need for countermeasures to address this crash type and technologies are being developed to do so. What is now important is a sense of urgency and the will to move forward with the implementation of these technologies.

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