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# MOTORCYCLE–HEAVY VEHICLE CRASHES: USA DATA AND IMPLICATIONS FOR OTHER PARTS OF THE WORLD

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## ABSTRACT

From 2015 to 2016, crash fatalities in the USA increased 2.6%, with two of the largest increases occurring for large trucks (+8.6%) and motorcycles (+5.1%). Little is known about motorcycle (MC) and heavy vehicle (HV) interactions. A two-phase study was conducted. Fatal Accident Reporting System data were examined to evaluate trends in MC–HV crashes and a substantial increase in fatalities over the past several years was found. Naturalistic driving study (NDS) data were used to characterize MC–HV safety-critical events (SCEs, including crashes and near-crashes). The review of NDS data revealed 11 SCEs involving MC–HV interactions that were investigated in depth. While existing NDS data can provide initial insights into the genesis of MC–HV SCEs, a larger study, preferably in a country with a high rate of MC ridership, is needed to better understand the problem space so that countermeasures to ameliorate these crashes can be developed.

Keywords: large trucks, motorcycles, naturalistic data, crashes, international

## 1. INTRODUCTION

Over the past 20 years, roadway fatalities have generally decreased in the USA. In 1988, there were 47,087 road fatalities in the USA, whereas in 2017 there were 37,133 (Insurance Institute for Highway Safety [IIHS], 2018). During this time span, there have been ups and downs in the fatality numbers. In 2014, there were 32,744 fatalities, which jumped to 35,485 in 2015. In 2016 and 2017, fatalities were 37,806 and 37,133, respectively. Thus, though the general 20-year trend has been downward, data show an increase in recent years.

A deeper dive into the fatality data shows that crashes involving heavy vehicles (HVs) and motorcycles (MCs) have also increased in recent years. Comparing findings from 2014 to 2016, fatalities resulting from crashes involving HVs increased 8.6%, and fatalities resulting from MC crashes increased 5.1% (National Highway Traffic Safety Administration [NHTSA], 2017; NHTSA, 2018a). In 2017, the percentage of fatalities resulting from HV crashes increased to its highest proportion since 1989 (NHTSA, 2017; NHTSA, 2018a). HVs are disproportionately represented in fatal crashes in the USA, where they constitute only 4% of registered vehicles but are involved in 9% of all fatal crashes (National Center for Statistics and Analysis [NCSA], 2019). Crashes involving HVs are often more severe than interactions with other vehicles because HVs weigh 20–30 times more than light vehicles (LVs) (NCSA, 2019; IIHS, 2001).

Given the large weight discrepancy between HVs and MCs, along with the increases in the numbers of registered MCs and HVs over the past 10 years (Federal Highway Administration, 2015), MC–HV interactions are of significant concern in terms of roadway fatalities. Indeed, the involvement of HVs and MCs in fatal crashes per vehicle mile traveled has increased (NHTSA, 2018c; NCSA, 2019). While studies have shown that MC–HV crashes are not the most common type of collision involving MCs, MC–HV crashes are associated with high crash severity (Chung and Song, 2018; Rifaat et al., 2012). For example, an analysis of 10 years of crash data from Iran determined that compared to MC–MC crashes, MC crashes with HVs increased pre-hospital death by 2.5 times (Sadeghi-Bazargani et al., 2018). However, there is a lack of specific data on MC–HV interactions and the factors contributing to these crashes. Considering the increasing trends in both MC ridership and the number of HVs on the road, MC–HV interactions are likely to increase. To reduce the number of fatal crashes, we must better understand why these crashes occur. Thus, there is a need to identify the factors involved in MC–HV crashes. Only with a clear understanding of these factors can countermeasures be developed to address this growing problem.

## 1.1 Naturalistic Driving Data

In naturalistic driving studies (NDSs), study participants drive instrumented vehicles as they would drive their personal or company vehicle. Video and vehicle data are generally collected continuously; that is, the data collection system begins collecting data as soon as the vehicle ignition starts and continues to record until the vehicle is turned off. This method enables researchers to see video of exactly what the driver was doing prior to a safety-critical event (SCE; e.g., crash), in addition to assessing the driving environment (e.g., road type, traffic conditions, and weather conditions). Continuous data collection also provides a greater amount of data for use in analyses as it captures more than just crash data. For instance, all near-crashes and close calls are recorded as well as baseline (normative/uneventful) data to be used as a comparison or control.

Naturalistic driving research has provided valuable information that has allowed research questions to be answered that could not be pursued with other data collection methods. For example, naturalistic data collection has been used in research on driver distraction as it allows for the identification of secondary tasks immediately before an SCE (Hammond et al., in press; Hammond et al., 2016; Olson et al., 2009). Naturalistic research led to a ban on texting by HV drivers in 2010 and a ban of all handheld cell phones for HV drivers in 2011. Naturalistic data collection has also been used to study driving time related to the Hours-of-Service regulations (Blanco et al., 2011), since with continuous driving data, it is possible to know driving hours without relying on paper logs.

Naturalistic driving data have also been used to examine how vehicles interact with each other and what factors lead to SCEs. For example, Hanowski et al. (2006) investigated the factors associated with LV–HV interactions using NDS data collected from LVs. After removing cases for which fault could not be determined, 64% of LV–HV interactions could be attributed to the behavior of the LV. A second study looked at SCEs involving LV–HV interactions from the HV's perspective (that is, data collected from HVs). Similar to the previous study, 78% of the recorded LV–HV SCEs were determined to have been initiated by the LV driver. In the current study, a similar method was used to characterize SCEs involving MCs and HVs based on NDS data. To our knowledge, this is first study to use NDS data for this purpose.

# 2. METHOD AND RESULTS

A two-phase approach was used to investigate MC–HV interactions. In both phases, the HVs included large trucks and buses (excluding school buses). The first phase examined data from the Fatality Analysis Reporting System (FARS; NHTSA, 2018b), a nationwide (USA) census that provides yearly data on fatal injuries resulting from motor vehicle crashes. The first-phase analysis focused on fatal crashes involving HVs and MCs from 2000 to 2017.

Figure 1 below shows fatal crashes involving only MCs, only HVs, and at least one MC and HV. Please note that the left vertical axis corresponds to fatal crashes involving only MCs (line with diamonds) and only HVs (line with squares), whereas the right vertical axis reflects fatal crashes involving at least one HV and at least one MC (line with triangles). For 2017, the FARS data indicate 5,109 fatal crashes involving MCs only, 4,387 involving HVs only, and 285 involving at least one MC and HV. The number of fatal crashes involving MCs alone increased by 3.34% from 2015 to 2017, whereas fatal crashes involving only HVs and both HVs and MCs have increased by 16.24% and 21.79% since 2015.

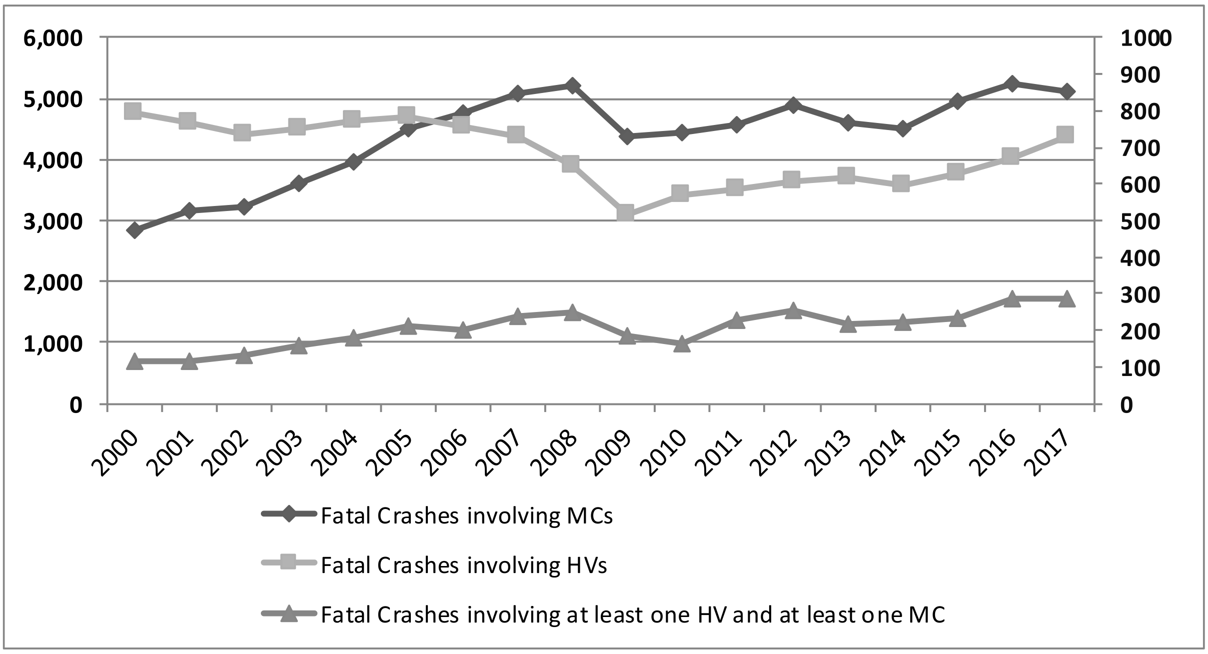

Figure 1. Fatal crashes involving HVs and MCs

The second phase analyzed naturalistic data collected by the Virginia Tech Transportation Institute in 2012 through 2015 from seven HV fleets across the USA (Boyle et al., 2016). For each vehicle, several video camera views were typically recorded (e.g., face, over-the-shoulder, front, rear, and right/left side views; see Figure 2), and vehicle sensors collected vehicle speed, Global Positioning System (GPS) data, braking intensity, steering input, forward range to the lead vehicle, and additional measures. Unlike police accident reports, which are used to collect data after a crash has occurred, naturalistic data collection enables researchers to (1) see exactly what the driver was doing prior to an SCE and (2) assess the driving environment (e.g., road type, traffic conditions, and weather conditions).

Figure 2. Five NDS camera images multiplexed into a single image

The NDS data were reduced by trained data analysts. The first step in this process was to run an event trigger program. Because of the large quantity of data obtained from the continuous data collection, it was necessary to create flags in the data to identify points of interest. To do this, the data were scanned for notable events, including hard braking, quick steering maneuvers, short time to collision (TTC), and lane deviations. To identify these events, previously established threshold values were used to flag instances in the video and quantitative data where the threshold values were met or exceeded. Trigger thresholds were originally developed using a sensitivity analysis of varying sensor values in an effort to maximize valid events and minimize invalid and missed events. These triggers are defined in Table 1.

Table 1. Trigger Definitions

| **Trigger** | **Description** |
|---|---|
| Longitudinal Acceleration | Deceleration greater than or equal to $\lvert 0.20\text{ g} \rvert$. Speed greater than or equal to 3.5 mph (1 mph for truck data). |
| TTC | A forward TTC value of less than or equal to 2 s, coupled with a range of less than or equal to 250 ft, a target speed of greater than or equal to 5 mph, a yaw rate of less than or equal to $\lvert 6^\circ/\text{s} \rvert$, and an azimuth of less than or equal to $\lvert 12^\circ \rvert$. |
| Swerve | Swerve value greater than or equal to $2^\circ/\text{s}^2$. Speed greater than or equal to 5 mph. |
| Lane Deviation | A lateral acceleration value of greater than 0.2 g (either left or right) while traveling greater than 25 mph with a lane distance off center greater than 1.4 m. |

Once the triggers were created, analysts reviewed each flagged event to determine if it was caused by a valid or invalid trigger. Valid events were those events where the recorded dynamic motion values were verified by video and other sensor data. Invalid events were those where the sensor readings were spurious due to a transient spike or some other anomaly, such as driving over a pothole (i.e., false positive). Valid events were classified into one of five SCE types, shown in Table 2 below. During this process, 4,102 SCEs were identified.

Table 2. SCE Definitions

| Trigger Type | Description |
|---|---|
| Crash | Any contact that the subject vehicle has with an object, either moving or fixed, at any speed. Also included are non-premeditated departures from the roadway where at least one tire leaves the paved or intended travel surface of the road. |
| Near-Crash | Any circumstance that requires a rapid evasive maneuver by the subject vehicle or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. |
| Crash-Relevant Conflict | Any circumstance that requires an evasive maneuver on the part of the subject vehicle or any other vehicle, pedestrian, cyclist, or animal that is less urgent than a rapid evasive maneuver (as defined above in near-crash), but greater in urgency than a normal maneuver to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. |
| Unintentional Lane Deviation | Any single vehicle situation where the subject vehicle unintentionally drifts or crosses over a lane line (e.g., into the shoulder or adjacent lane) where there is NOT a hazard present (e.g., guardrail, steep ditch, or vehicle), or the hazard is never closer than one lane width to the subject. If the hazard is closer than one lane width, the event should be classified as crash-relevant, near-crash, or crash, as appropriate. |

Once valid events were identified and classified as one of the above SCE types, analysts answered a set of questions related to each event. These questions included information on the conflict itself, such as the pre-incident movements of each vehicle involved, the types of vehicles involved, precipitating events (e.g., braking by the lead vehicle), and evasive maneuvers. Analysts also answered questions on the environment, including weather, lighting, surface conditions, number of lanes, and relation to junction (e.g., intersection). MC–HV interactions were observed in 11 of the valid 4,102 SCEs, (0.27%).

The MC–HV SCEs included two (18.18%) near-crashes and nine (81.82%) crash-relevant conflicts (Table 3). Non-MC-involved SCEs included 35 crashes (0.86%), 864 near-crashes (21.12%), 1,973 crash-relevant conflicts (48.23%), and 1,219 unintentional lane deviations (29.80%). The MC-involved events all occurred during dry road conditions with no adverse weather. Additionally, 90.81% of non-MC-involved events occurred during dry road conditions. Nearly all (90.91%) MC-involved events occurred during daylight compared to 75.62% of non-MC-involved events.

Table 3. Event Severity in SCEs Involving Motorcycles and Heavy Vehicles

| Event Severity | MC-Involved Frequency | MC-Involved Percent | Non-MC-Involved Frequency | Non-MC-Involved Percent |
|---|---|---|---|---|
| Crash | 0 | 0.00% | 35 | 0.86% |
| Near-Crash | 2 | 18.18% | 864 | 21.12% |
| Crash-Relevant Conflict | 9 | 81.82% | 1,973 | 48.23% |
| Unintentional Lane Deviation | 0 | 0.00% | 1,219 | 29.80% |

The prevalence of different roadway features in the MC-involved and non-MC-involved SCEs was assessed. MC-involved events were observed in both divided (63.64%) and non-divided (36.36%) roadways. The SCEs were most frequently observed in traffic flow with some restricted movement (Level of Service B, 54.55%) and free-flowing traffic with leading traffic present (Level of Service A2, 18.18%). The events included several different junction relationships, including driveway/alley access, interchange areas, intersections, parking lot entrances/exits, and non-junctions. The SCEs occurred most frequently on interstate roads (63.64%), followed by business or industrial roads (27.27%) and residential roads (9.09%).

Non-MC-involved SCEs were also observed in divided (54.16%) and non-divided (28.36%) roadways, as well as in roadways with one-way traffic (16.01%) and no traffic lane (1.47%). While these SCEs were observed in all traffic densities, they were most common in traffic flow with some restricted movement (Level of Service B, 38.90%) and free-flowing traffic with no lead traffic (Level of Service A1, 25.93%). Non-MC-involved SCEs occurred most frequently in non-junction (54.19%), intersection and intersection-related (16.43%), and interchange (15.32%) junctions. The localities in which the MC-involved and non-MC-involved SCEs occurred were similar; however, SCEs occurred at airports in 11.46% of non-MC-involved SCEs (compared to 0% of MC-involved SCEs).

One of the MC-involved events was an interaction between an HV and three MCs. The three MCs were driving as a caravan, maneuvering the roadway with similar behavior. As MCs may drive in multiples, this MC–HV crash configuration may be worthy of exploration in future studies.

## 3. DISCUSSION

The current study included an analysis of FARS data (fatal crashes recorded on roadways in the USA). In the most recent year of available FARS data (2017), there were 5,109 fatal MC-only crashes, 4,387 fatal HV-only crashes, and 285 fatal MC–HV crashes. Although the proportion of fatal MC–HV crashes among total crashes in the USA is relatively small (approximately 1%), this crash type is growing (NHTSA, 2018b). This is not surprising given that MC ridership has nearly doubled from 4.3 million in 2000 to 8.4 million in 2014 (Federal Highway Administration, 2015).

This study also reanalyzed NDS data collected from HVs from 2012 to 2015 (Boyle et al., 2016) to identify MC–HV interactions. Using the approach developed by Hanowski et al. (2007) to investigate LV–HV events, the characteristics of all MC–HV interactions (11) identified in the HV NDS dataset were detailed. Although the small number of events does not lend itself to statistical analysis, the method used in the current study can be utilized or further developed for future studies.

In countries where MC ridership is more prominent than in the USA, MC–HV crashes might make up a larger subset of all crashes. For example, in Malaysia, MCs constitute approximately 47% of all motorized vehicles, with yearly average MC ridership of 104.5 billion km (64.9 billion miles; Abdul Manan et al., 2012). Furthermore, approximately 14% of all road fatalities (860 MC riders) in Malaysia result from MC–HV crashes (Abdul Manan et al., 2012).

Previous research conducted in Malaysia has reported on the high risk of crashes and casualties related to the interaction between MCs and other vehicles, especially between MCs and HVs. Hamidun et al., (2019) conducted an analysis on 5 years of police crash data (2011–2015) to examine the characteristics of HV crashes in Malaysia. Out of 7,026 cases of HV crashes recorded during that period, 59.4% of them (4,175 cases) were crashes involving an HV and MC. Almost one-third of these cases resulted in fatalities. In addition, motorcyclists on Malaysian roads are more vulnerable to the risk of fatal injuries due to the higher likelihood of multi-vehicle crashes. The percentage of fatal cases was found to be higher for multi-vehicle crashes involving MCs in Malaysia compared to single MC crashes (Abdul Manan et al., 2018).

In a mixed-traffic environment with a high MC population, space and volume constraints could potentially influence the riding behaviors of motorcyclists, especially during congestion. Ibrahim et al. (in press) conducted a small-scale naturalistic motorcycle riding study in Malaysia to investigate the impact of lane sharing on the riding behaviors of motorcyclists. The study found that 96.5% of the recorded SCEs occurred while the motorcyclists were committing non-lane-based movements, including lane-filtering and lane-splitting movements. The study also reported that the likelihood of a near miss related to these movements was significantly influenced by the types of vehicles and roads. Another small-scale naturalistic motorcycle riding study conducted by Ibrahim et al. (2018) reported significantly higher odds of a near miss in the events related to lane changing and overtaking maneuvers either committed by MCs or other motorists.

Collectively, the previous studies outline a critical role for the management of potential conflict between MCs and other motorists on Malaysian roads, especially the conflicts involving MCs and HVs. However, there remain several aspects of motorcyclists' riding behaviors in a mixed-traffic environment about which relatively little is known, especially regarding crash causation and mitigation. A local MC crash investigation study has revealed that more than 60% of all investigated crashes occurred when other motorists (i.e., not the MC) were at fault (Zainal et al., 2018). On the other hand, motorcyclists' riding behaviors were also reported as one of the main causes of a near miss in a conflict involving MC and other vehicles (Ibrahim et al., 2018). Thus, a deeper understanding is needed of behavioral and other crash causal factors for effective countermeasures.

A large-scale NDS with instrumentation of both MCs and HVs would be beneficial to obtain further in-depth information to explain the complexities of MC–HV crash causation and mitigation in Malaysia and other countries with a similar vehicle composition and traffic settings. One particular benefit is the opportunity to collect real-world data that can explain the parameters for the development of crash avoidance technologies. For instance, data on MC overtaking behavior in a mixed-traffic environment is crucial to determine the required detection range in the development of motorcycle detection technologies.

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