Prevalence of driver physical factors leading to unintentional lane departure crashes

Jessica B. Cicchino and David S. Zuby
Insurance Institute for Highway Safety, Arlington, Virginia

ABSTRACT
Objective: Some lane-keeping assist systems in development and production provide autonomous braking and steering to correct unintentional lane drift but otherwise require drivers to fully control their vehicles. The goal of this study was to quantify the proportion of drivers involved in unintentional lane drift crashes who would be unable to regain control of their vehicles to inform the design of such systems.

Methods: The NHTSA's National Motor Vehicle Crash Causation Survey collected in-depth, on-scene data for a nationally representative sample of 5,470 U.S. police-reported passenger vehicle crashes during 2005–2007 that occurred between 6 a.m. and midnight and for which emergency medical services were dispatched. The physical states of drivers involved in the 631 lane drift crashes in the sample, which represented 259,034 crashes nationally, were characterized.

Results: Thirty-four percent of drivers who crashed because they drifted from their lanes were sleeping or otherwise incapacitated. These drivers would be unlikely to regain full control of their vehicles if an active safety system prevented their initial drift. An additional 13% of these drivers had a nonincapacitating medical issue, blood alcohol concentration (BAC) ≥ 0.08%, or other physical factor that may not allow them to regain full vehicle control. When crashes involved serious or fatal injuries, 42% of drivers who drifted were sleeping or otherwise incapacitated, and an additional 14% were impacted by a nonincapacitating medical issue, BAC ≥ 0.08%, or other physical factor.

Conclusions: Designers of active safety systems that provide autonomous lateral control should consider that a substantial proportion of drivers at risk of lane drift crashes are incapacitated. Systems that provide only transient corrective action may not ultimately prevent lane departure crashes for these drivers, and drivers who do avoid lane drift crashes because of these systems may be at high risk of other types of crashes when they attempt to regain control. Active lane-keeping assist systems may need to be combined with in-vehicle driver monitoring to identify incapacitated drivers and safely remove them from the roadway if the systems are to reach their maximum potential benefit.

Introduction

In 2014, single-vehicle run-off-road crashes accounted for 38% of fatal passenger vehicle crashes and 20% of passenger vehicle crashes with nonfatal injuries in the United States (Insurance Institute for Highway Safety 2016). Head-on collisions and sideswipes, which may result from unintentional lane departures, together represented an additional 14% of fatal crashes and 10% of nonfatal injury crashes involving at least one passenger vehicle in 2014.

Vehicle-based countermeasures have been developed to prevent unintentional lane departures. Electronic stability control (ESC), an established collision avoidance technology that helps vehicles maintain control on curves and wet roads, reduces single-vehicle fatal crash risk by 49% (Farmer 2010). Lane departure warning, which tracks the vehicle's position within the lane and warns drivers who cross lane markings without activating the turn signal, and lane-keeping assist, which resists the vehicle's movement out of the lane or helps direct the vehicle back into the lane through braking or steering adjustments, can potentially prevent lane drifts without control loss that would not be addressed by ESC.

Vehicle systems in production and development are increasingly using more forceful braking and steering adjustments to keep vehicles within highway lanes. Because the driver plays a less active role in lane keeping with these systems but would need to later assume full control of the vehicle, it is important to know whether a meaningful proportion of drivers involved in unintentional lane departures would be physically incapable of safe driving when required to regain control.

A few studies have examined the contribution of the driver's physical condition to lane departure crashes. Among police-reported crashes in Kansas during 1999–2008, lane departure crashes, which included run-off-road, head-on, and sideswipe with opposing vehicle crashes, were more likely than non-lane-departure crashes to involve driver sleep, illness, medical condition, or alcohol involvement (Roy and Dissanayake 2011). Similarly, U.S. fatal single-vehicle run-off-road crashes during 1991–2007 were more likely to involve a driver with a blood alcohol content (BAC) equal to or greater than 0.01% or a fatigued driver than fatal single-vehicle crashes that occurred on the roadway (Liu and Subramanian 2009).
Others have reported the prevalence of physical contributing factors to lane departure or run-off-road crashes or near crashes. In a sample of 394 run-off-road crashes with injuries at 20 high-crash sites on 2-lane rural roads in Texas during 2003–2008, driver fatigue and alcohol involvement each were contributing factors to 12% of crashes (Lord et al. 2011). Among 50 unintentional lane departure crashes examined from a German insurance database, a driver's physical condition or health problem was a factor in 66% (Kuehn et al. 2015). This study included only crashes causing injury or damage to a third party, so many single-vehicle run-off-road crashes were excluded. Eleven percent of the 122 run-off-road crashes or near crashes in a naturalistic driving study were related to driver fatigue or impairment (McLaughlin et al. 2009).

The type of information and consistency with which it is collected in police-reported and insurance crash databases can be limited. Likewise, McLaughlin et al.'s (2009) naturalistic study included few crashes, most of which too minor to report to the police. The National Motor Vehicle Crash Causation Survey (NMVCCS) conducted by the NHTSA performed in-depth crash investigations using a sample of U.S. crashes requiring emergency medical response and collected more complete information on driver state than typically is found in police reports. Using NMVCCS data, Liu and Ye (2011) reported that the critical reason leading to run-off-road crashes was a driver physical factor in 23% of these crashes, and Kusano and Gabler (2014) similarly reported that a driver physical factor was the critical reason in 22% of crashes relevant to lane departure warning.

Prior research examining driver state in run-off-road or lane departure crashes, including those using NMVCCS data, varied considerably in their definitions of the relevant crash types. For example, few separated crashes where the vehicle ran off the road due to loss of control from the lane drifts that can potentially be prevented by lane-keeping assist. Studies also differed in their inclusion of multiple-vehicle on-road crashes and in their exclusion of crashes resulting from intentional lane changes. The current study sought to more thoroughly quantify the proportion of drivers who were involved in unintentional lane departure crashes and were incapacitated or affected by other physical factors that may not have allowed them to regain full vehicle control. We used NMVCCS data and carefully considered the types of lane departure crashes that would be most relevant to lane-keeping assist systems. A secondary goal was to examine the prevalence of physical factors leading to lane drift crashes with serious or fatal injuries.

**Method**

**NMVCCS database**

The NMVCCS database includes a nationally representative sample of 5,470 U.S. police-reported crashes that occurred between 6 a.m. and midnight during July 2005–December 2007, involved at least one passenger vehicle that was towed from the scene and for which emergency medical services were dispatched (NHTSA 2008). Crashes can be weighted to represent more than 2 million crashes nationally meeting the time of day, date, and severity specifications outlined above. Trained investigators arrived at the crash scene and documented characteristics of the crash, photographed the crash scene and vehicles, and interviewed crash participants, witnesses, and first responders. Complete data sets that included more than 600 data elements were generated for the first 3 vehicles involved in the collision. Detailed crash summaries were also written for each crash. To qualify for the study, one of these vehicles must have been present when the investigator arrived at the crash scene, and a complete police crash report must have been available.

NHTSA researchers reconstructed the chain of events leading to the crash. Working backwards from the crash, the core elements of this chain of events included (1) the critical precrash event, which was the event that made the crash inevitable; (2) the critical reason for the critical precrash event, which was the immediate reason why the critical event occurred; and (3) the movement prior to the critical crash envelope, which described the vehicle's movement prior to the event that placed the vehicle on an imminent collision path. The critical reason was assigned to a single vehicle involved in the crash.

**Lane departure crashes**

The study focused on unintentional lane departures by passenger vehicles assigned the critical reason in a crash and on the subset of these crashes considered to be lane drifts. Unintentional lane departures included crashes where the crash type (i.e., first harmful event) was categorized as a roadside departure or the critical precrash event for the vehicle assigned the critical reason was the vehicle traveling over the lane line or off the edge of the road. Crashes were excluded if the subject vehicle purposefully left the lane, which was defined as crashes where the subject vehicle's movement prior to the critical envelope was changing lanes, passing, merging, or turning; the critical event was turning at an intersection; or the crash type was a sideswipe while changing lanes, turning across the path of another vehicle, or right angle. Backing crashes and end departures (where a vehicle departs the end of the roadway after approaching it perpendicularly, such as at a T-intersection) were also excluded.

Lane drift crashes were defined as the subset of unintentional lane departure crashes that could potentially be addressed by active lane-keeping assist systems because the driver drifted out of the lane. These excluded crashes where the subject vehicle lost control or was avoiding another crash and crashes where the critical reason for the crash was traveling too fast for a curve, vehicle failure, or a roadway or weather factor. Crashes with control loss were defined as those where the critical precrash event was a control loss event (i.e., loss of control due to a blowout/flat tire, stalled engine, disabling or nondisabling vehicle problem, poor road conditions, traveling too fast for conditions, jackknife event, cargo shift, or another or unknown cause); the preimpact stability indicated that the vehicle was skidding; or the crush type was a roadside departure with control loss or a forward impact with another vehicle because of control loss.

A vehicle was considered to be avoiding another crash if the movement prior to the critical crash envelope was an avoidance maneuver to another possible crash; the critical reason for the precrash event was an inadequate or incorrect evasive maneuver; the critical precrash event was avoiding a nonmotorist, object, or animal in roadway; or the crash type was a...
roadside departure or forward collision due to avoiding a collision.

Too-fast-for-curve and control loss crashes were excluded from drift crashes because these crash categories would not be expected to be addressed by lane-keeping assist systems and because they would be best addressed by existing or other developing systems. NMVCCS data were collected during 2005–2007, so few vehicles in the data set had ESC, which could address loss-of-control crashes; curve speed warning systems could best address crashes due to traveling too fast on a curve.

The SAS code (Version 9.4; SAS Institute, Cary, NC) used to define unintentional lane departure and lane drift crashes appears in Appendix A (see online supplement).

**Critical reason for precrash event**

Possible critical reasons for crashes used in this study are listed and defined in Table 1. NHTSA researchers categorized critical reasons related to the driver's physical state as sleeping, physical impairment of the ability to act, or other/unknown physical factor. The critical reason was characterized as a physical impairment of the ability to act if the driver was passed out or otherwise impaired due to a medical reason, as an "other" physical factor if the driver was passed out or physically impaired due to drugs or alcohol or if multiple physical factors contributed to the crash, and as "unknown" when it was unclear what the specific nature of the driver's physical impairment was.

In the current study, we combined BAC, the NHTSA-assigned critical reason, and the crash summaries of drivers assigned a critical physical factor by NHTSA to recategorize critical physical factors as sleeping, otherwise incapacitated, BAC ≥ 0.08% and not incapacitated, other medical factor, and other or unknown physical factor (Table 1). BAC was obtained from either medical records or the police report. The crashes of drivers with BACs ≥ 0.08% who were assigned critical reasons in the current study were considered to be due to physical factors regardless of the NHTSA-assigned critical reason.

For crashes where the NHTSA-assigned critical reason was a physical impairment of the ability to act or an other/unknown physical factor, crash summaries first were searched for key words (i.e., seizure, diabetic, stroke, heart attack, blackout, pass out, faint, lose consciousness, and permutations of these terms) and then were examined further. Descriptions of physical and medical factors in the crash summaries were confirmed by investigators with medical personnel when possible but also drew from reports from police, the driver, passengers, witnesses, and family of the driver.

Among these crashes, drivers were considered to have been otherwise incapacitated (i.e., incapacitated for a reason other than sleep) at the time of the crash if the crash summary mentioned a seizure, diabetic shock or event, heart attack, or stroke or the driver was reported to be blacked out or have lost consciousness. Descriptions of diabetic events did not always clarify whether the driver lost full consciousness but were categorized as incapacitation. The critical reason was considered to be another medical factor if the driver was conscious at the time of the crash but the crash description mentioned that a medical condition other than diabetic shock was the reason for the crash (e.g., dizziness, driver swerved due to coughing fit, driver lost control due to extreme pain, driver's foot went numb). We kept NHTSA's assignment of sleeping as a critical reason if the driver did not have a BAC ≥ 0.08%; if a driver was sleeping and did have a BAC ≥ 0.08%, the driver was considered to be incapacitated. Finally, a driver was assigned a critical reason of BAC ≥ 0.08% and not incapacitated if they met those criteria.

### Table 1. Definitions of critical reasons. a

| Type/factor                  | Definition                                                                                       |
|------------------------------|--------------------------------------------------------------------------------------------------|
| **Physical**                 |                                                                                                  |
| Sleeping                     | Driver is asleep; driver's BAC was <0.08% or was unknown                                         |
| Other incapacitation         | Driver lost consciousness prior to crash due to seizure, diabetic event, stroke, heart attack, drug or alcohol impairment, or other reason unrelated to fatigue |
| BAC ≥ 0.08%, not incapacitated| Driver had BAC ≥ 0.08% and was conscious prior to crash; if the driver's BAC was ≥ 0.08% and the driver was incapacitated or asleep, the critical reason was categorized as other incapacitation |
| Medical factor, not incapacitated | Driver's medical condition was reason for crash and driver was conscious prior to crash |
| Other or unknown physical factor | Driver's physical functioning was reason for the crash due to other than listed above or unknown cause |
| **Other**                    |                                                                                                  |
| Distraction                  | Driver failed to recognize situation because attention is directed at event, object, person, or activity inside of vehicle or because of daydreaming |
| Inadequate or incorrect evasive action | Driver failed to execute reasonable evasive action (e.g., braking only instead of braking and steering) or executed wrong evasive action (e.g., braking instead of steering) |
| Too fast for conditions or to respond to the actions of others | Driver traveled at speed greater than a reasonable standard of safe driving |
| Too fast for curve           | Driver negotiated curve at a speed greater than what is prudent                                  |
| Overcompensation             | Driver overcorrects to a situation requiring adjustment in path or velocity                      |
| Poor directional control     | Driver fails to maintain degree of control reasonably expected of a good driver                 |
| Other driver factor          | Known factor related to driver other than those listed above. Includes inadequate surveillance, misjudgment of gap between vehicles or another vehicle's speed, following too closely, false assumption of others' actions, illegal maneuver other than speeding, aggressive driving behavior, turned with obstructed view, panic/freezing |
| Unknown driver factor        | Unknown driver-related factor                                                                    |
| Vehicle factor               | Vehicle failure (e.g., lights, brakes, tires, engine, transmission, suspension), cargo shift, jackknife, inadequate road design (e.g., poor sight distance, roadway geometry that does not meet AASHTO standards, inadequate/incorrect signs or signals), poor road condition, rain, snow, fog, glare |
| Weather or roadway factor    |                                                                                                  |

aAASHTO = American Association of State Highway and Transportation Officials.

### Analyses

The weighted prevalence of various characteristics of unintentional lane departure and drift crashes is reported. When results are reported for fatal or serious injury crashes, this refers to crashes in which anyone was killed or seriously injured (i.e., K or A on the KABCO scale).
Results

The database contained 1,591 unintentional lane departure crashes where the critical reason was assigned to a passenger vehicle, which when weighted represented 737,679 (35%) of the 2,100,285 total weighted NMVCCS crashes with critical reasons assigned to a passenger vehicle. Table 2 indicates that 631 of these crashes were lane drifts. When weighted, lane drifts represented 259,034 crashes, which comprised 35% of unintentional lane departures and 12% of total NMVCCS crashes with critical reasons assigned to passenger vehicles.

Table 3 describes characteristics of all unintentional lane departure crashes and of the subset that were considered lane drifts and of drivers in these crashes. Most were run-off-road crashes and involved a single vehicle. About a quarter of each involved fatal or serious injuries. Teenage drivers were underrepresented in lane drift crashes relative to all unintentional lane departure crashes, whereas older drivers were overrepresented. Driver seat belt use was higher in unintentional lane departure crashes than among the subset involved in lane drift crashes.

Drivers did not attempt an avoidance maneuver in the majority of lane drift crashes, especially in those involving serious or fatal injuries, but they did attempt an avoidance maneuver in most unintentional lane departure crashes. A larger proportion of drivers in all unintentional lane departures left and then reentered the roadway than among the subset that drifted out of their lane. Twelve percent of drivers involved in lane drift crashes and 17% involved in lane drift crashes with fatal or serious injuries had BACs ≥ 0.08%, although BAC was unknown for most drivers.

Vehicle, weather/atmospheric, and roadway characteristics of all unintentional lane departure crashes and those that were lane drifts are summarized in Table 4. Very few vehicles had ESC. Most crashes of all severities occurred in daylight, when it was not raining or snowing, and on roads with speed limits less than 50 mph. About half of all lane departure crashes occurred on curves, and the majority of lane drift crashes occurred on straightaways.

Table 5 summarizes the critical reasons leading to all unintentional lane departure crashes and lane drift crashes of all severities and those involving serious and fatal injuries. Sleeping or other incapacitation was the critical reason in 34% of lane drift crashes of all severities and in 42% of lane drift crashes involving fatal or serious injuries. Any physical factor, including having a BAC ≥ 0.08% without being incapacitated, was the critical reason in 47% of lane drift crashes of all severities and 56% of lane drift crashes with fatal or serious injuries.

Among drivers involved in lane drift crashes of all severities, reasons for incapacitation included seizures (42 drivers, 5% weighted among drift crashes); blackouts due to alcohol use, drug use, or nonuse of necessary prescription drugs (23 drivers, 4% weighted); diabetic events (16 drivers, 2% weighted); heart attacks (4 drivers, <1% weighted); strokes (3 drivers, <1% weighted); other medical reasons (15 drivers, 3% weighted); and unknown reasons (17 drivers, 2% weighted).

Discussion

Although vehicle safety systems are becoming increasingly automated, drivers currently are required to take full control of their vehicles at some point after the systems are activated. For lane-keeping assist systems, more active versions may steer or brake to keep a driver in his or her lane when the system senses that the vehicle is unintentionally drifting without requiring additional input from the driver, but many provide only a transient correction and require the driver to retake control. Yet, data from NMVCCS indicate that a large proportion of drivers involved in lane drift crashes are asleep or otherwise incapacitated and would be unlikely to regain full control of their vehicle that was kept within the lane by a lane-keeping assist system. The proportion of sleeping and otherwise incapacitated drivers in lane drift crashes is even higher among crashes with serious or fatal injuries. Thus, lane drift crashes may only be temporarily averted, or different crash types other than lane departure crashes may occur as an unintended consequence if these incapacitated drivers are kept on the road by active safety systems.

In-vehicle driver monitoring that can detect early signs of a physical event could be combined with active safety systems to direct a driver’s vehicle to a safe stop off of the roadway if the system detects that the driver is incapacitated (Ridella et al. 2015). Providing warnings as current lane departure warning systems do may be helpful for waking drivers who are asleep. Although no research has assessed whether lane departure warning systems wake real-world sleeping drivers in enough time to prevent a crash after they have left their lanes, simulator studies have demonstrated that warnings of various modalities can attract the attention of fatigued drivers (DeRosario et al. 2010; Kozak et al. 2006; Rimini-Doering et al. 2005).

Jermakian (2011) estimated that lane departure warning could prevent 3% of police-reported crashes of all severities, 5% of nonfatal injury crashes, and 23% of fatal crashes. There is not yet evidence that lane departure warning is living up to this potential. The Highway Loss Data Institute (2011, 2012a, 2012b, 2015a, 2016a, 2016b) examined the effectiveness of lane departure warning systems from 6 manufacturers and found no consistent effects on the rates of insurance claims that cover damage to at-fault vehicles, which is the type of claim that would likely follow a single-vehicle run-off-road crash, when vehicles with systems were compared with the same vehicle models without a system.

Results of the current study indicate that lane departure warning systems may not reach their full potential because a substantial proportion of drivers involved in crashes relevant to the system are incapacitated or otherwise not in a physical...
Table 3. Crash and driver characteristics for vehicles assigned critical reasons in all lane departure crashes and the subset that are lane drift crashes (weighted percentage).

| Crash type                                      | Lane drift crashes | All intentions lane departure crashes |
|------------------------------------------------|--------------------|--------------------------------------|
| Run-off-road                                    | 72                 | 84                                   |
| Sideswipe/angle, opposite direction             | 8                  | 6                                    |
| Head-on                                         | 11                 | 18                                   |
| Forward collision with parked car or other stationary object, on road | 6                  | 5                                    |
| Sideswipe/angle, same direction                 | 1                  | 2                                    |
| Other                                           | 2                  | <1                                   |
| Number of vehicles in crash                     |                    |                                      |
| One                                             | 76                 | 84                                   |
| Two                                             | 20                 | 14                                   |
| Three or more                                   | 4                  | 2                                    |
| Maximum injury severity in crash                |                    |                                      |
| Fatal                                           | 6                  | 4                                    |
| Serious (incapacitating)                        | 21                 | 21                                   |
| Moderate, minor, or injury of unknown severity   | 51                 | 50                                   |
| No injury                                       | 20                 | 24                                   |
| Unknown                                         | 2                  | 2                                    |
| Driver age                                      |                    |                                      |
| <20                                             | 8                  | 19                                   |
| 20–34                                           | 37                 | 40                                   |
| 35–54                                           | 30                 | 25                                   |
| 55–69                                           | 13                 | 8                                    |
| 70+                                             | 9                  | 4                                    |
| Unknown                                         | 2                  | 3                                    |
| Driver seat belt use                            |                    |                                      |
| Yes                                             | 71                 | 77                                   |
| No                                              | 20                 | 16                                   |
| Unknown                                         | 9                  | 7                                    |
| Driver attempted avoidance maneuver             |                    |                                      |
| No                                              | 68                 | 32                                   |
| Unknown                                         | 17                 | 12                                   |
| Yes                                             | 15                 | 5                                    |
| Braking and steering                            | 6                  | 6                                    |
| Steering, no braking                            | 6                  | 3                                    |
| Braking, no steering                            | 3                  | 0                                    |
| Other maneuver                                  | <1                 | <1                                   |
| Driver left and reentered roadway               |                    |                                      |
| Yes                                             | 9                  | 26                                   |
| No                                              | 91                 | 74                                   |
| Driver BAC                                      |                    |                                      |
| 0–0.99%                                         | 15                 | 9                                    |
| ≥0.08%                                          | 12                 | 8                                    |
| Not tested, refused, otherwise unknown          | 73                 | 83                                   |

state to respond to warnings appropriately. Surveys of owners with lane departure warning and lane-keeping assist systems (Braitman et al. 2010; Eichelberger and McCartt 2014, 2016) and an observational study of the activation status of lane departure warning in vehicles serviced at dealerships (Reagan and McCartt 2016) show that drivers find warnings from these systems annoying and frequently turn them off, which also hampers effectiveness.

The proportion of lane drift crashes that is attributable to driver physical factors in the current research was higher than in most prior studies, including those that have used the NMVCCS database. There are a few explanations for this discrepancy. One is that studies differ in the driver states considered to be physical factors and in the data collection methods used. For example, prior studies using NMVCCS (Kusano and Gabler 2014; Liu and Ye 2011) did not include alcohol impairment in their definitions of physical factors, and the police-reported data used in other studies may undercount physical contributing factors that could be difficult for police to determine after a crash has occurred.

A second difference between the current and prior studies is how lane drift crashes were defined. We took advantage of the many variables available in NMVCCS data to ensure inclusion of multivehicle crashes resulting from lane departures and exclusion of crashes involving lane changes or turning, avoiding another crash, control loss, speeding too fast for a curve, or vehicle or roadway failures. Other studies using NMVCCS data, for instance, did not exclude control loss crashes with preimpact skidding by the subject vehicle (Kusano and Gabler 2014; Liu and Ye 2011).

This study is not without limitations. A major weakness is that NMVCCS did not include crashes that occurred between midnight and 6 a.m., which is when many lane departure crashes occur. In 2014, 19% of all and 28% of fatal single-vehicle run-off-road crashes occurred during these hours (Insurance Institute
Table 4. Vehicle, weather/atmospheric, and roadway for vehicles assigned critical reasons in all lane departure crashes and the subset that are lane drift crashes (weighted percentage).

| Type/reason                          | Lane drift crashes | All unintentional lane departure crashes |
|--------------------------------------|--------------------|-----------------------------------------|
|                                      | All severities     | Fatal and serious injuries              |
|                                      | (unweighted N = 631)| (unweighted N = 124)                    |
|                                      | Fatal and serious injuries |
|                                      | (unweighted N = 1,591)| (unweighted N = 269)                    |
|                                      | Fatal and serious injuries |
|                                      | (unweighted N = 269) |
| Vehicle has ESC                      |                     |                                         |
| Yes                                  | 4                  | 2                                       |
| No                                   | 94                 | 96                                      |
| Unknown                              | 2                  | 1                                       |
| Raining or snowing                   |                     |                                         |
| Yes                                  | 9                  | 18                                      |
| No                                   | 91                 | 82                                      |
| Unknown                              | <1                 | <1                                      |
| Lighting condition                   |                     |                                         |
| Daylight                             | 65                 | 63                                      |
| Dawn or dusk                         | 5                  | 7                                       |
| Dark but lighted                     | 9                  | 7                                       |
| Dark                                 | 20                 | 23                                      |
| Unknown                              | <1                 | <1                                      |
| Speed limit (mph)                    |                     |                                         |
| Under 40                             | 39                 | 34                                      |
| 40–49                                | 28                 | 25                                      |
| 50–59                                | 21                 | 20                                      |
| 60–69                                | 6                  | 11                                      |
| 70 or greater                        | 4                  | 9                                       |
| No statutory limit or unknown        | 1                  | 1                                       |
| Roadway alignment and departure side |                     |                                         |
| Straight                             |                     |                                         |
| Depart left                          | 26                 | 21                                      |
| Depart right                         | 37                 | 27                                      |
| Curve                                |                     |                                         |
| Depart left                          | 17                 | 25                                      |
| Depart right                         | 20                 | 26                                      |

for Highway Safety 2016). It is probable that the prevalence of driver physical factors differs during these hours compared to daytime hours; in particular, it is likely that the prevalence of alcohol-impaired driving, incapacitation due to alcohol impairment, and sleeping is higher during these hours than reported at other times of day, whereas the prevalence of medical incapacitation is likely lower.

BAC was not available for most crash-involved drivers and consequently the percentage of drivers with high BACs was almost certainly higher than what was reported. Thus, though the study reports that 12% of drivers in lane drift crashes had BACs ≥ 0.08%, it should be considered that at least that percentage of drivers had high BACs and likely more. Not all illnesses were verified with medical personnel, so the illnesses named as

Table 5. Critical reasons in all lane departure crashes and the subset that are lane drift crashes (weighted percentage).

| Type/reason                          | Lane drift crashes | All unintentional lane departure crashes |
|--------------------------------------|--------------------|-----------------------------------------|
|                                      | All severities     | Fatal and serious injuries              |
|                                      | (unweighted N = 631)| (unweighted N = 124)                    |
|                                      | Fatal and serious injuries |
|                                      | (unweighted N = 1,591)| (unweighted N = 269)                    |
|                                      | Fatal and serious injuries |
|                                      | (unweighted N = 269) |
| Physical                             |                     |                                         |
| Sleeping                             | 17                 | 7                                       |
| Other incapacitation                 | 17                 | 7                                       |
| BAC ≥ 0.08%, not incapacitated       | 8                  | 7                                       |
| Medical factor, not incapacitated    | 2                  | 1                                       |
| Other or unknown physical factor     | 3                  | 1                                       |
| Subtotal: Sleeping or incapacitated  | 34                 | 14                                      |
| Subtotal: Physical factors           | 47                 | 22                                      |
| Other                                |                     |                                         |
| Distraction                          | 22                 | 16                                      |
| Poor directional control             | 11                 | 8                                       |
| Overcompensation                     | 2                  | <1                                      |
| Too fast for conditions or to respond to the actions of others | 1 | 13 |
| Too fast for curve                   | —                  | 10                                      |
| Inadequate or incorrect evasive action | —               | 4                                       |
| Other driver error                   | 7                  | 5                                       |
| Unknown driver factor                | 10                 | 4                                       |
| Vehicle factor                       | —                  | 4                                       |
| Weather or roadway factor            | —                  | 3                                       |
| Total                                | 100                | 100                                     |
reasons for incapacitation may not always be accurate. Lane-keeping assist systems will not function in the absence of lane lines, and it was unknown whether lane markings were visible on study roads. It is likely that lane-keeping assist systems would not have been operational if present in some study crashes due to insufficient, missing, or obscured lane markings.

Data from NMVCCS are not recent. A larger proportion of vehicles on the road have ESC now than during the 2005–2007 data collection period (Highway Loss Data Institute 2015b), and the prevalence of characteristics leading to all unintentional lane departures would likely be different today than it was then because many loss-of-control crashes would be prevented by ESC. However, ESC would not be expected to affect lane drift crashes.

In conclusion, drivers were asleep or otherwise incapacitated in about a third of lane drift crashes occurring between 6 a.m. and midnight and in nearly half of lane drift crashes resulting in fatal or serious injuries. As lane-keeping assist systems that actively keep drivers in their lanes continue to be developed, designers should account for the large proportion of drivers who will be potentially shielded from an initial lane departure crash but who nevertheless remain unable to regain control of their vehicles. These drivers remain at a high risk of crashing if their lane-keeping assist systems are incapable of bringing their vehicles safely to a stop off the roadway.

**Funding**

This work was supported by the Insurance Institute for Highway Safety.

**ORCID**

Jessica B. Ciccino http://orcid.org/0000-0003-4337-518X

**References**

Braitman KA, McCartt AT, Zuby DS, Singer J. Volvo and Infiniti drivers’ experiences with select crash avoidance technologies. *Traffic Inj Prev*. 2010;11:270–278.

DeRosario H, Soler A, Tenas J, Dominguis M, Echeverria M. Effective patterns of sleep warnings based on the physiologic and behavioural reactions of users. In: *Proceedings of European Conference on Human Centered Design for Intelligent Transport Systems*. Lyon, France: Humanist VCE; 2010:49–58.

Eichelberger AH, McCartt AT. Volvo drivers’ experiences with advanced crash avoidance and related technologies. *Traffic Inj Prev*. 2014;15:187–195.

Eichelberger AH, McCartt AT. Toyota drivers’ experiences with dynamic radar cruise control, pre-collision system, and lane-keeping assist. *J Safety Res*. 2016;56:67–73.

Farmer CM. *Effects of Electronic Stability Control on Fatal Crash Risk*. Arlington, VA: Insurance Institute for Highway Safety; 2010.

Highway Loss Data Institute. Buick collision avoidance features: initial results. *HLDI Bull*. 2011;28(22):1–7.

Highway Loss Data Institute. Mercedes-Benz collision avoidance features: initial results. *HLDI Bull*. 2012a;29(7):1–22.

Highway Loss Data Institute. Volvo collision avoidance features: initial results. *HLDI Bull*. 2012b;29(9):1–11.

Highway Loss Data Institute. 2013–2015 Honda collision avoidance features. *HLDI Bull*. 2015a;32(22):1–13.

Highway Loss Data Institute. Predicted availability of safety features on registered vehicles—a 2015 update. *HLDI Bull*. 2015b;32(16):1–13.

Highway Loss Data Institute. Mazda collision avoidance features: an update. *HLDI Bull*. 2016a;33(3):1–14.

Highway Loss Data Institute. 2013–15 Subaru collision avoidance features. *HLDI Bull*. 2016b;33(6):1–10.

Insurance Institute for Highway Safety. [Unpublished analysis of data from the Fatality Analysis Reporting System and National Automotive Sampling System General Estimates System]. Arlington, VA: Author; 2016.

Jermakian JS. Crash avoidance potential of four passenger vehicle technologies. *Accid Anal Prev*. 2011;43:732–740.

Kozak K, Pohl J, Birk W, et al. Evaluation of lane departure warnings for drowsy drivers. *Proc Hum Fact Ergon Soc Annu Meet*. 2006;50:2400–2404.

Kuehn M, Hummel T, Bende J. Analysis of car accidents caused by unintentional run off road. In: *Proceedings of the 24th International Technical Conference on the Enhanced Safety of Vehicles*. Washington, DC: NHTSA; 2015, 1–9. Paper No. 15-0245.

Kusano KD, Gabler HC. Comprehensive target populations for current active safety systems using national crash databases. *Traffic Inj Prev*. 2014;15:753–761.

Liu C, Subramanian R. Factors Related to Fatal Single-Vehicle Run-off-Road Crashes. Washington, DC: NHTSA; 2009. Report No. DOT HS 811 232.

Liu C, Ye TJ. Run-off-Road Crashes: An On-scene Perspective. Washington, DC: NHTSA; 2011. Report No. DOT HS 811 500.

Lord D, Brewer MA, Fitzpatrick K, Gedipally SR, Peng Y. Analysis of Roadway Departure Crashes on Two-Lane Rural Roads in Texas. Austin, TX: Texas Department of Transportation; 2011. Report No. FHWA/TX-11/0-6031-1.

McLaughlin SB, Hankey JM, Krauer SG, Dingus TA. *Contributing Factors to Run-off-Road Crashes and Near-Crashes*. Washington, DC: NHTSA; 2009. Report No. DOT HS 811 079.

NHTSA. National Motor Vehicle Crash Causation Survey: Report to Congress. Washington, DC: Author; 2008. Report No. DOT HS 811 059.

Reagan JJ, McCartt AT. Observed activation status of lane departure warning and forward collision warning of Honda vehicles at dealership service centers. *Traffic Inj Prev*. 2016;17:827–832.

Ridela SA, Kang JJ, Kitazaki S. The potential for adaptive safety through in-vehicle biomechanical and biometric monitoring. In: *Proceedings of the 24th International Technical Conference on the Enhanced Safety of Vehicles*. Washington, DC: NHTSA; 2015, 1–12. Paper No. 15-0377.

Rimini-Dorner M, Altmueller T, Ladstaetter U, Rossmeier M. Effects of lane departure warning on drowsy drivers’ performance and state in a simulator. In: *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. Iowa City: University of Iowa; 2005;88–95.

Roy U, Dissanayake S. Comparison of factors associated with run-off-road and non-run-off-road crashes in Kansas. *Journal of the Transportation Research Forum*. 2011;50:69–86.