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Analyses of Rear-End Crashes and Near-Crashes in the 100-Car Naturalistic Driving Study to Support Rear-Signaling Countermeasure Development

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16. Abstract

The 100-Car Study collected unique pre-crash data that might help to overcome the limitations of police reports and, thus, might help identify possible countermeasures. Such information includes the timing and location of where drivers were looking, the timing of accelerator release and brake application, as well as the drivers' time and force modulation of the brake pedal. The goal of this task is to gain a better understanding of what driver behaviors and performance contribute to rear-end events, the vehicle kinematics that influence the event, and the potential of enhanced rear-signaling systems to alert following drivers or provide additional cues regarding lead vehicle dynamics. The goal of Task 1 of the current project was to analyze results of 100-Car Study to attain in-depth understanding of rear-end crashes, near-crashes, and incidents as a basis for identifying enhanced signal light characteristics and functions. In addition, a sample of baseline braking events was analyzed for characterization of normal braking maneuvers and comparison of normal braking to rear-end conflict braking. These analyses provided further insight into the causes, characteristics, and potential countermeasures for rear-end crashes. In addition, the data provided justification for various deceleration criteria for enhanced rear-lighting systems.

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EXECUTIVE SUMMARY

Summary of Previous Work

Rear-end crashes are the most frequently occurring type of collision, accounting for approximately 29 percent of all crashes and resulting in a substantial number of injuries and fatalities each year. Rear-end collisions in which the lead vehicle is stopped or moving very slowly prior to the crash account for the majority of these crashes. Over the years several initiatives have addressed the problem of rear-end crashes, with limited success. The most public of these ventures was the center high-mounted stop lamp (CHMSL), which was required to be present on automobiles beginning with model year 1986. The long-term effectiveness of the CHMSL has leveled off at about a 4-percent reduction in rear-end crashes, which means there is still much room for improvement. To this end, the National Highway Traffic Safety Administration (NHTSA) contracted with the Virginia Tech Transportation Institute (VTTI) in 1999 to conduct a series of tests resulting in recommendations for enhanced rear lighting and signaling systems. This section briefly summarizes this earlier work, the full details of which can be found in Lee, Wierwille, and Klauer (2002); Wierwille, Lee, and Dehart (2003); and Wierwille, Lee, and Dehart (2005).

The goal of this previous research effort was to develop and test a small number of enhanced rear-lighting concepts that have the potential to reduce the number of rear-end collisions. These enhanced concepts are intended to supplement rather than replace conventional rear signaling. This research was conducted in three phases, corresponding to three tasks. Task 1 involved investigating all previous efforts to develop enhanced rear-lighting systems, determining the causes of rear-end crashes, and developing a short list of rear-lighting alternatives to be tested in future research efforts under this project.

Task 2 consisted of two experiments to design and optimize systems with regard to four dependent measures (Attention-Getting Rating, Discomfort-Glare Rating, Horizontal Peripheral Detection Angle, and Diagonal Peripheral Detection Angle) while also taking system complexity into account. Experiment 1 evaluated 17 configurations and was conducted using white lights and clear lenses to provide a consistent comparison across all configurations. The results showed that the Traffic Clearing Light (TCL), a lamp with a motorized reflector moving in an "M-sweep" pattern, was the top candidate for a high-level signal (e.g., for imminent crash warning), while a pair of centrally located alternating halogen lamps would be optimal for a stopped/slowly-moving vehicle signal. Experiment 2 evaluated four configurations and three lens colors (clear, amber, and red). The results showed that the TCL was superior to the alternating pair configurations in attention-getting and peripheral detection and would thus be best used as the high-level signal with tinted lenses in either red or amber. The results also suggested that the high-output halogen alternating pair with dispersive lenses represents the best available configuration for the stopped/slowly-moving vehicle signal with tinted lenses in either red or amber.

Task 3 was directed toward refinement and initial field testing of two imminent-warning signals. These signals are intended to direct the following driver's visual glance to the lead vehicle as it brakes rapidly to a stop and then stands on the pavement. The signals can also be used to warn of an impending rear-end crash. The Task 3 on-road experiment was conducted on the Virginia Smart Road in Blacksburg, Virginia, using a surrogate vehicle (drawn by a lead vehicle) containing conventional lighting and the two imminent-warning lighting configurations (the TCL and an improved alternating pair, or IAP, as shown in Figure ES1). In a preliminary experiment, the alternating pair was re-optimized in terms of frequency, light output, and startup characteristics so that it would be suitable for use as an imminent warning signal.

Figure ES1. The TCL (left) and IAP (right) imminent-warning lighting signals as used in the Task 3 Experiment of the previous study.

Seventy-two ordinary drivers, split into three groups, participated in the Task 3 experiment. Driver subjects were purposely distracted by in-vehicle tasks as the lead (surrogate) vehicle underwent hard braking. Responses were compared for the conventional and two enhanced lighting groups. Results showed improvements in brake activation times of 0.25 to 0.35 s, corresponding to 15 to 30 ft (4.6 to 9.1 m) of additional stopping distance for the enhanced lighting. The TCL was just slightly better than the IAP. The results also demonstrate a learning effect between the first and second exposures, with braking performance improving with second exposure. Other measures suggested the eyes are drawn to the forward view more quickly with the enhanced lighting. Final system recommendations and specifications were provided at the end of this task, along with program recommendations.

One of the program recommendations was to conduct a field operational test (FOT) of the two enhanced rear-signaling systems with the following specifications:

- Test the TCL and the IAP separately, with each system using a kick circuit with high initial voltage and then running each configuration at 14.8 V for improved daytime visibility.
- Place the signals higher on the vehicle than they were placed for the Task 3 Smart Road tests (based on participant feedback).
- Attenuate the brightness of the signals at nighttime.
- Activate the signal when the deceleration is greater than 0.35*g*. This will serve as a high deceleration signal to the following driver.
- Once the deceleration drops below 0.15*g*, add 5 s of timeout before deactivating the signal. In most cases, this should keep the light active as the vehicle brakes to a stop and for a reasonable period of time afterwards, thus addressing the stopped-lead-vehicle rear-end crash case.

TASK 1 OF CURRENT PROJECT

NHTSA decided that there were further considerations that should be addressed before these enhanced rear signaling systems could undergo a full FOT. These considerations can be described as:

- What does the 100-Car database have to say about the causes and potential lighting countermeasures for rear-end crashes? (The 100-Car Study was a large-scale naturalistic study conducted in the interim between the first rear-lighting study and the current study.) This question is the focus of this Task 1 report.
- How can we best measure the following driver's response to the enhanced rear signaling? This measurement question has been addressed in Task 2 of the current study.
- How should the FOT be conducted in terms of location, logistics, participant population, etc.? This research design question was the focus of Task 3 of the current study.

The 100-Car Study collected unique pre-crash data that might help to overcome the limitations of police reports and, thus, might help identify possible countermeasures. Such information includes the timing and location of where drivers were looking, the timing of accelerator release and brake application, as well as the drivers' time and force modulation of the brake pedal. The goal of this task is to gain a better understanding of what driver behaviors and performance types contribute to rear-end events, the vehicle kinematics that influence the events, and the potential of enhanced rear-signaling systems to alert following drivers or provide additional cues regarding lead-vehicle dynamics.

There were 7,024 events coded as Conflict with Lead Vehicle (LV) or Conflict with Following Vehicle (FV). These events include Conflict with LV and Conflict with FV events recorded for all drivers. Each rear-end event was coded as a crash, near-crash, or incident, as follows:

- Crash: Any contact with an object, either moving or fixed, at any speed, in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, or animals.
- 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. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle's capabilities. As a guide, subject-vehicle braking greater than $0.5g$ or steering input that results in a lateral acceleration greater than $0.4g$ to avoid a crash constitutes a rapid maneuver.
- Incident: Any circumstance that requires a crash avoidance response on the part of the subject vehicle or any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a "normal maneuver" to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal maneuver" for the subject vehicle is defined as a control input that falls outside of the 99 percent confidence limit for control input as measured for the same subject. This category also includes cases resulting in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object when, due to apparent unawareness on the part of the driver, pedestrians, cyclists, or animals, there is no avoidance maneuver or response. Extraordinarily close proximity is defined as a clear case in which the absence

of an avoidance maneuver or response is inappropriate for the driving circumstances (e.g., speed, sight, distance, etc.).

Rear-end crashes, near-crashes, and incidents were analyzed using data collected from the 100-Car Study in order to provide insights into the role of rear-signaling systems in crash prevention and aid in the design of enhanced rear-signaling systems. As indicated, there were 7,024 rear-end events logged in the database: 27 crashes, 450 near-crashes, and 6,547 incidents. The vast majority of these events (88%) were conflicts with a lead vehicle; data for conflicts with a following vehicle were captured, but represent a minority of cases (about 12%). Of the 7,024 observed rear-end events, 45 percent involved a decelerating lead vehicle, 38 percent involved a stopped lead vehicle, 2 percent involved a slower moving lead vehicle, and 15 percent occurred under various other situations. Crashes were predominately characterized by situations in which the lead vehicle was stopped, whereas near-crashes and incidents were more evenly distributed across instances of both stopped and decelerating lead vehicles. The majority of rear-end crash events (59%, or 16 out of 27) involved a stopped lead vehicle, while 22 percent (6 out of 27) occurred under conditions of a decelerating lead vehicle.

Analysis of 100-Car data found that most drivers are attentive and able to detect and respond to a stopped or decelerating lead vehicle. The overwhelming majority of drivers, for example, responded to a decelerating lead vehicle by braking within approximately 2 s (75^{th} percentile); 99 percent of drivers in near-crashes and 95 percent of drivers in incidents responded to a decelerating lead vehicle by braking. In contrast, 47 percent of crash-involved drivers failed to brake and/or steer in response to a decelerating lead vehicle. Data suggest that failure to respond (or delays in responding) to a stopped or decelerating lead vehicle is generally a result of distraction, and in particular, improper allocation of visual attention. Of the 6,177 rear-end events involving a conflict with a lead vehicle, 26 percent involved a distracted driver. Approximately 87 percent of rear-end crashes in which the driver struck the lead vehicle included some form or degree of driver distraction; this was much higher than the rates of distraction observed for near-crashes (42%) and incidents (25%). About 70 percent of drivers in near-crashes and incidents were looking forward at the onset of lead vehicle braking, while only 40 percent of crash-involved drivers were looking forward at the onset of lead vehicle braking. Drivers whose focus of visual attention was directed away from the forward roadway at the onset of lead vehicle braking were found to have longer brake reaction times (an average of 600 ms longer) compared to drivers who were looking forward (for incidents). Although rare, long glances (more than 2 s) away from the forward roadway played a key role in crash events; this finding underscores the importance of developing a system that can reorient drivers to the forward roadway under conditions of a decelerating or stopped lead vehicle. For instance, about 64 percent of crash-involved drivers had eyes-off-road time over 2 s.

Analyses of rear-end events also suggest that the vast majority of drivers involved in incidents and near-crashes were not necessarily following too closely given their speed at the onset of lead-vehicle braking. Approximately 90 percent of drivers were observed to have time-to-collision values at or above 2 s at the onset of lead-vehicle braking (Question #3). Furthermore, braking levels associated with decelerating lead vehicles were not so extreme that following drivers could not “out brake” and avoid the lead vehicle. Observed lead-vehicle decelerations were characterized by moderate braking levels (for both near-crashes and incidents). For example, peak lead-vehicle deceleration levels across all events (crashes, near-crashes, and incidents) were generally under 0.55*g*; only 15 percent of the cases involved a lead vehicle decelerating above 0.55*g*. Following drivers tended to respond to a decelerating lead vehicle with substantially higher deceleration, particularly for near-crash events. Median peak deceleration levels for near-crash events were 0.74*g*, and the 90th percentile value was 0.94*g*. Thus, the opportunity or ability to avoid the crash by braking does not appear to be the key underlying problem for lead-vehicle deceleration cases; rather, the problem appears to stem from following driver allocation of visual attention after the onset of lead-vehicle braking.

A major finding from the analysis of rear-end events is that time and again, the measures being examined showed that there was virtually no distinction to be made between crashes and near-crashes, while incidents looked very different from both crashes and near-crashes. However, there was one important area where this was not true: *the eyeglance data for crashes looks very different from the eyeglance data for near-crashes*. With the eyeglance data, near-crashes and incidents look quite similar. Eyeglance patterns appear to be the most significant predictors of whether a near-crash situation evolves into a crash for conflicts with lead and following vehicles. This argues strongly for a signal that more effectively draws the FV driver's eyes to the forward view, and to provide more information to the FV driver regarding heavy braking and stopping by the LV.

An additional, separate analysis was performed to establish the parameters of *baseline* braking events. These were braking events lasting at least 3 s and captured using VTTI data-mining software. After data-mining approximately 20 percent of the 100-Car complete database, nearly 500,000 of these events were captured. The baseline braking events were then filtered to include only those meeting certain criteria relevant to the questions of interest. This filtering resulted in a final baseline braking event dataset containing just over 189,000 events. Some of the baseline braking events may also have been included in the 100-Car event database as a crash, near-crash, or incident.

One of the primary purposes of the baseline braking event analysis was to determine the potential impact of various hard-braking activation criteria. One proposed criterion is for a hard-braking signal that activates with peak deceleration >0.7*g*. In the baseline braking event database, this level occurred very infrequently (0.05 percent of braking events, or once out of every 2,000 braking events, or once per 100 h of driving, or once per 3,000 mi). A European study found that such a signal would be activated even less frequently, at approximately once every 4,300 braking events. A second proposed criterion is for activation at peak deceleration >0.35*g*. This type of signal would occur much more frequently (approximately 7% of braking events, or once out of every 14 braking events, or 1.4 times per 1 h of driving, or 79 times per 1,000 mi of driving). Following are some potential percentile activation criteria:

- 0.1 percent of braking events had a peak deceleration of >0.63*g*,
- 0.5 percent of braking events had a peak deceleration of >0.51*g*,
- 1 percent of braking events had a peak deceleration of >0.47*g*, and
- 5 percent had a peak deceleration >0.37*g*.

Further implications of various activation criteria are discussed later in the baseline braking event section of this report.

IMPLICATIONS OF 100-CAR DATA ANALYSES FOR REAR-SIGNALING SYSTEM DESIGN

- Data suggest that a successful rear-signaling system will work to redirect driver visual attention to the forward roadway, particularly under cases of prolonged driver visual distraction (eyes-off-road time greater than 2 s). Evaluation of enhanced rear-signaling systems, therefore, should focus on the system's ability to draw the drivers' attention to the forward roadway, particularly in cases where eyes-off-road time exceeds 2 s (these are relatively rare situations). Driver glances away from the forward roadway longer than 2 s are more common for crashes than either incidents or near-crashes. Approximately 64 percent of crash-involved drivers had eyes-off-road times above 2 s compared to under 15 percent for near-crash- and incident-involved drivers. Substantial benefits can be gained if the system is able to induce drivers to brake within the first 1.5 s of lead-vehicle braking onset (Question #1).
- Driver gazes to the forward roadway (front windshield) do not guarantee that drivers are attentive and processing relevant cues. Approximately 40 percent of crash-involved drivers had their gaze directed out the front windshield at the time of lead-vehicle braking onset. Drivers in this situation often subsequently looked away from the forward view after the lead vehicle began braking. These drivers may not have detected the braking signal, or if they did detect the signal, did not process it as a relevant cue (these were often in stop-and-go traffic, where there had been many prior lead-vehicle brake-light activations). This makes a strong argument that additional salient cues may be needed to alert drivers to the onset of lead-vehicle braking events (Question #2).
- Data suggest that a deceleration threshold of 0.4*g* and above would serve as a viable triggering criterion for the onset of an enhanced rear-signaling system. Almost all crashes and near-crashes were above this threshold, while very few of the baseline braking events reached this threshold. This criterion, backed by the 100-Car data, is quite close to the 0.35*g* criterion proposed in the original study, and which was based on engineering judgment and deceleration tests.
- A rear-signaling system that communicates moderate to hard lead-vehicle decelerations has the potential to decrease the incidence of rear-end near-crashes and incidents. For example, a system that signaled hard lead-vehicle decelerations (peak braking above 0.55*g*) could potentially address 56 percent (109 out of 194) of the near-crash events (Question #6). Using a peak deceleration criterion of 0.35*g* to trigger the onset of a rear-signaling system would lead to system activations in approximately 90 percent of all following-vehicle deceleration rear-end events (crashes, near-crashes, and incidents), and 60 percent of all lead-vehicle deceleration rear-end events.
- Available crash data suggest that rear-signaling systems which are designed to alert drivers to the presence of a stopped lead vehicle have the potential, if effective, to reduce the incidence of rear-end crashes. The majority of observed rear-end crashes in the sample (81%) were collisions with a stopped lead vehicle. Such a system would also benefit safety by reducing the incidence of near-crashes and incidents (Question #6).
- A passive rear-signaling system that extinguishes somewhat after a vehicle comes to a complete stop should provide benefit by reducing a substantial percentage of collisions with stopped lead vehicles, while reducing annoyance caused by extended signaling after a vehicle is stopped. Data suggest this type of signal would address approximately

45 percent (10 out of 22) of stopped-lead-vehicle crashes (Question #6). The proposed activation/deactivation criteria for the Task 2 tests will allow us to assess the effectiveness of the proposed 5-second timeout (beyond the deactivation due to deceleration criteria). The "stopped" signal is simply a continuation of the high-deceleration signal – it will not be activated if the vehicle does not decelerate above the set threshold. Crashes into stopped vehicles suggest that these are occurring shortly after the lead vehicle has stopped. Consequently, extending the activation period by means of timeout should be effective.

ANALYSIS HIGHLIGHTS BY QUESTION

Question #1: What was the distribution of response time of the "following" driver to the lead-vehicle brake application? What is the relationship between response time, deceleration, and braking behavior of "following" drivers to the onset of the brake lamps[1] of the lead vehicle? These data may help to provide an indication of real-world reaction times and the braking patterns of drivers.

- The distributions of brake reaction times between near-crashes and incidents are not strikingly different, but there is evidence to suggest that drivers in incidents had faster brake response times than drivers in near-crashes. The advantage may be due to the immediate response within the 1.5 s of the onset of the lead vehicle's brake lamps.
- No strong linear relationship was found between driver brake-reaction time and peak deceleration (r= -0.08). A marginal relationship was, however, found between braking response time and averaged deceleration (r = 0.24), suggesting that drivers with longer brake response times also had higher sustained levels of deceleration.
- Drivers who were glancing away from the forward roadway at the onset of lead-vehicle braking had substantially longer brake-reaction times (about 600 ms longer on average) compared to drivers whose visual focus was on the forward roadway.

Question #2: To what extent were "following" drivers distracted and thus did not see the lead-vehicle braking? What was the focus of visual attention of the "following" driver (e.g., mirror, inside object, passenger, etc.)?

- Drivers are routinely engaged in activities that divert their attention from the forward roadway while driving. Executing driving-related activities themselves (e.g., scanning the mirrors) appear to be a significant and common source of driver distraction.
- Different patterns of distraction-inducing activities emerged for crashes, near-crashes, and incidents. Dining and daydreaming were strongly associated with crashes. Use of wireless devices (cells phones in particular) contributed to near-crashes and incidents, as did passenger-related distraction. Cell-phone use, and in particular conversing (talking/listening) on a cell phone while driving, was one of the top distraction-causing activities contributing to near-crashes and incidents (based on simple counts of occurrence). Cognitive distraction appears to be a common underlying theme – this type

[1] Rear lamps that are illuminated upon the application of the brake pedal are defined as "stop lamps" by FMVSS 108. To prevent any confusion with a stopped vehicle signal in this work, the terms "brake lamps" are used to describe "stop lamps."

of distraction arguably contributes to cell phone conversation, looked but did not see, and daydreaming.

- Driver gazes to the forward roadway (front windshield) do not guarantee that drivers are attentive and processing relevant cues. Approximately 40 percent of crash-involved drivers had their gaze directed out the front windshield at the time of lead-vehicle braking onset. This makes a strong argument that additional salient cues may be needed to alert drivers to the onset of lead-vehicle braking events. Only about 13 percent of crash-involved drivers were looking down in the cab near the center console area.
- Long glances away from the roadway (over 2 s) are much more common in crashes than in either of the two other event types. Specifically, approximately 64 percent of crash-involved drivers had eyes-off-road times above 2 s compared to approximately 15 percent and 13 percent of near-crash- and incident-involved drivers, respectively.
- In cases where the driver's eyes were off the forward view at the time the lead-vehicle brake lamps came on, there is evidence from previous studies that certain lamp types might have drawn the driver's eyes forward more quickly.

Question #3: To what extent were "following" drivers so close that they simply could not "outbrake" the lead vehicle? Were lead vehicles decelerating too quickly for the "following" vehicle to stop given the headway and speed prior to lead-vehicle braking?

- The patterns of vehicle headways and time-to-collision values at the onset of lead-vehicle braking across near-crash and incident events are very similar and suggest that the vast majority of drivers were not necessarily following too closely at the onset of lead-vehicle braking.
- Although some drivers adopted short following distances (the 25th percentile values fell under 1 s for both near-crashes and incidents), Time-to-Collision (TTC) values were well above imminent crash levels (e.g., 2 s) suggesting that the "following" drivers were maintaining an acceptable distance from the lead vehicle given their speed at the onset of lead-vehicle braking.
- Data are consistent with the hypothesis that late detection of lead-vehicle braking may lead to heavier braking by the following driver. Peak deceleration levels for following drivers suggest that drivers involved in near-crashes had delays detecting lead-vehicle braking onset relative to drivers involved in incidents. Drivers in near-crashes had higher median peak deceleration levels (0.74*g*) than drivers in incidents (0.51*g*); mean brake response times were 1.3 and 1.0 s for near-crashes and incidents, respectively.
- Drivers appear to be more responsive and aware of the severity of events unfolding in the forward view as opposed to those unfolding behind them.

Question #4: To what extent were "following" drivers involved in crashes, near-crashes, and incidents making lane changes and failing to notice a slower car ahead?

- Lane changes and merges rarely lead to a conflict with a lead vehicle. When such conflicts do occur, the LV is usually stopped, decelerating, or changing lanes.
- There does not appear to be a large amount of distraction associated with lane-change and merge events. For those events that do involve distraction at some point during the event, about 25 percent involve task-related distraction (related to the lane change or merge).

- Eyeglance analysis indicates that the driver's eyes were usually forward when the lead-vehicle brake lamps came on and that the eyes-off-road percentage during the course of the event was not unusual (13.3% eyes-off-road over all severities).
- The overall results do not present any indication that lane-change and merge conflicts with a LV would require different countermeasures than those that might be effective for other categories of conflict with lead vehicle.

Question #5: What were the vehicle speeds and headways prior to the point of closest headway?

- Crashes and near-crashes appear to have similar profiles in many cases. For example, distributions for mean TTC values for crashes closely resemble those for near-crashes. This suggests that driver actions taken immediately before the event strongly influenced the outcome of rear-end conflicts.
- Crashes tended to occur at lower speeds than near-crashes or incidents. Detailed examination revealed that the lower crash speeds observed for crashes are attributable, in part, to the environment and the pre-crash maneuver taken by the following driver. The vast majority of near-crashes (69%) and incidents (62%) occurred at non-junctions, while only 36 percent of crashes occurred at non–junction points. Drivers involved in near-crashes and incidents also tended to be going straight at a constant speed (45% and 44%, respectively); only 12 percent of crash-involved drivers were driving straight at a constant speed (most were decelerating in traffic).

Question #6: What proportion of rear-end events involve lead vehicle stopped, mild braking, hard braking, or just going slow without braking?

- Events triggered by a decelerating lead vehicle tend to involve moderate to heavy braking by the lead vehicle. In near-crash situations where the lead vehicle is decelerating, for example, approximately 56 percent of the lead-vehicle peak decelerations (109 out of 194) were above 0.55*g*'s, and 22 percent involved moderate braking (peak deceleration between 0.25 and 0.55*g*'s).
- The majority of observed rear-end crashes in the sample (81%) were collisions with a stopped lead vehicle.
- A rear-signaling system that extinguishes somewhat after a vehicle comes to a complete stop using a timeout system should provide benefit by reducing a substantial percentage of collisions with stopped lead vehicles, while reducing annoyance caused by extended signaling after a vehicle is stopped. Data suggest this type of signal would address approximately 45 percent (10 out of 22) of stopped-lead-vehicle crashes.

Question #7: What avoidance maneuvers did the driver take (e.g., just braking, steering, nothing, both)?

- Following-vehicle driver response to an event involving a lead vehicle overwhelmingly involved braking, with the FV driver braking in 84 percent of all events and braking and steering in 10 percent of all events. In nearly half of the crashes, there was no driver reaction to the event. This clearly indicates distraction/inattention, since closing distance cues are quite strong at short distances.
- Braking seems to be the preferred or instinctual FV-driver response to a severe LV maneuver (such as being stopped or braking hard), while a wide range of FV driver responses were found for milder LV maneuvers (such as moving at a slower constant speed or braking softly).
- Short and long TTCs resulted in more varied responses by the FV driver, while moderate TTCs resulted in braking about 90 percent of the time. At the shortest TTC values, drivers chose to both brake and steer 14 percent of the time, indicating that braking alone may not have been enough to prevent a crash. The distributions of FV driver responses with respect to TTC were fairly similar for all responses, especially for TTCs of less than 2 s.

Question #8: What were the braking levels of drivers who had near-crashes versus those in crashes versus those just braking to a stop sign or traffic signal? Are there factors that can reliably classify situations leading to high-braking from those leading to low-braking events?

- A set of baseline intersection approaches was used, based on 50 observed intersection clusters. There were 32 near-crashes, 320 incidents, and 1,102 baseline events in the final dataset used for this question.
- Some of the reduced categorical variables appear to be associated with higher severity, including poor weather, darkness, reduced traffic flow, curved sections of road near the intersection, location away from open countryside, and decreased use of a lap/shoulder belt.
- These analyses do not contradict previous conclusions regarding the potential efficacy of enhanced rear lighting systems.

Question #9: What are the influences of traffic, roadway environment, ambient light, and other contributing factors on the risk of rear-end events? What was the distribution of locations of rear-end events (e.g., intersections, freeway junctions, mid-block, etc.)?

- Male drivers were over-represented in rear-end crashes, as has been found in previous crash database analyses (61% of participants were male, but they accounted for 75% of rear-end crashes). This equates to males being 1.2 times more likely to be involved in a rear-end crash than females. However, females were involved in 50 percent of the near-crashes, even though only 39 percent of participants were female (thus females were 1.3 times as likely to be involved in a near-crash).

- Drivers in the 25- to 34-year-old age group were 1.9 times as likely to be involved in rear-end crashes as other age groups (17% of participants were in this age group, but they accounted for 33% of rear-end crashes).
- More specifically, 25- to 34-year-old males were overrepresented in rear-end crashes (17% of participants were 25- to 34-year-old males, but they accounted for 29% of rear-end crashes). This sex/age group was 1.7 times as likely to be involved in rear-end crashes than other sex/age groups, which accounts for much of the age and sex overrepresentation discussed in the previous two bullets.
- There were 44 different precipitating event categories in the dataset, but most events fell into 22 categories concerning lead- and subject-vehicle kinematics and lane changes. Altogether, 100 percent of crashes, 97 percent of near-crashes, and 98 percent of incidents are covered in these 22 precipitating event categories.
- Weather analysis results indicated that most rear-end events occur in clear weather conditions, as had been found in previous studies. However, a conflict with a lead or following vehicle may be more likely to result in a crash or near-crash when an unfavorable weather condition is present.
- Although most events occurred on dry roads, a conflict with a lead or following vehicle occurring on wet roads was more likely to result in a crash or near-crash than was a conflict occurring on dry roads, which was more likely to result in an incident.
- There was no clear influence of environmental light on event severity, although most events occurred in the daylight.
- Most events occurred on straight, level roads. However, when a conflict with a lead or following vehicle occurred on a curved section of road rather than on a straight section of road, it was increasingly likely to result in a near-crash or crash rather than an incident.
- Conflicts that occurred in intersections, intersection-related areas, or entrance/exit ramp locations were more likely to result in crashes than those occurring in non-junction locations. Over 60 percent of crashes occurred in intersection and intersection-related locations, while more than 60 percent of both near-crashes and events occurred in non-junction locations.
- Conflicts occurring in business/industrial locations were more likely to result in a crash than were conflicts occurring in open country and residential areas. However, business/industrial was the most common location type for all event severities.
- Over 60 percent of the rear-end crashes occurred in what would be considered the best two traffic flow and density situations: free flow and flow with some restrictions.
- For crashes, the most common pre-incident maneuver was decelerating in traffic lane, which accounted for 44 percent of the rear-end crashes. For both near-crashes and incidents, on the other hand, the most common maneuver was going straight at a constant speed, at about 44 percent for each.
- When a conflict was coded as impaired due to distraction, it was more likely to result in a crash than when it was coded as no apparent impairment.
- Incidents are not always good predictors of crashes. In examining the factors explored in Question #9, near-crashes are generally much more closely aligned with crashes than are incidents.

Baseline Braking Event Analysis

- One proposed activation criterion for hard braking is peak deceleration >0.7*g*. A hard-braking signal activated by this criterion would make up only 0.05 percent of braking events. This rate is approximately equal to:
  - Once out of every 2,000 braking events;
  - Once per 100 h of driving; or
  - Once per 3,000 mi.
- Another proposed criterion for a hard-braking signal is >0.35*g* peak deceleration. Events meeting this criterion made up approximately 7 percent of braking events. This rate is approximately equal to:
  - Once out of every 14 braking events;
  - 1.4 times per 1 h of driving; or
  - 49 times per 1,000 mi of driving.
- The criterion which seems to have the least overlap between baseline events and conflict events (near-crashes and incidents) is >0.4*g* peak deceleration. Events meeting this criterion made up approximately 3 percent of baseline braking events (compared with 75 percent of crash and near-crash events). This rate is approximately equal to:
  - Once out of every 33 braking events;
  - 0.6 times per 1 h of driving; or
  - 21 times per 1,000 mi of driving.
- Peak deceleration varies according to event severity. For example, median peak deceleration was 0.19*g* for baseline driving, 0.52*g* for incidents, and 0.74*g* for near-crashes.
- There appears to be a relationship between speed at the start of the braking event and peak velocity. For example, almost half of the very low deceleration category (<0.1*g*) occurred at the lowest starting velocity, while 70 percent of the highest deceleration category events (>0.7*g*) occurred at the highest starting velocity.
- Median following-vehicle time headway was shorter for near-crashes (1.38 s) and incidents (1.53 s) as compared to baseline braking (3.11 s).
- Drivers with a peak deceleration greater than 0.7*g* apparently did so without regard to FV headway.
- Braking events generally led to a shorter headway between the lead and following vehicles. For example, the 50th percentile for starting headway was 3.1 s, while the 50th percentile for ending distance was 2.9 s, a 6-percent decrease.
- As braking level increased, events were increasingly likely to end in a stop and less likely to end in slowing, acceleration, or reversion to the same speed. This final disposition was determined 10 s after the braking event began.
  - With a >0.7*g* activation criterion, 54 percent of events resulted in a stop, 43 percent in a slowing, and 3 percent in reversion to steady speed.
  - With a >0.35*g* activation criterion, 49 percent of events resulted in a stop, 49 percent in a slowing, and 1 percent each in acceleration or reversion to steady speed.
- Braking event duration can be characterized as follows:
  - Mean duration of 9.3 s.
  - Standard deviation of 8.5 s.
  - Median of 6.2 s (as compared to 4.0 s for incidents and 3.3 s for near-crashes).

    - 5th percentile of 3.2 s (only 5% of braking events lasted less than 3.2 s)
    - 95th percentile of 26.8 s (only 5% of events lasted more than 26.8 s)
- Time to full stop can be characterized as follows:
    - Mean duration of 8.1 s.
    - Standard deviation of 5.5 s.
    - Median of 6.7 s.
    - 5th percentile of 2.3 s (only 5% of events lasted less than 2.3 s)
    - 95th percentile of 18.6 s (only 5% of events lasted more than 18.6 s)

INTRODUCTION

OBJECTIVE

The 100-Car Study collected unique pre-crash data that might help to overcome the limitations of police reports and, thus, might help identify possible countermeasures. Such information includes the timing and location of where drivers were looking, the timing of accelerator release and brake application, as well as the drivers' time and force modulation of the brake pedal. The goal of this task is to gain a better understanding of what driver behaviors and performance contribute to rear-end events, the vehicle kinematics that influence the event, and the potential of enhanced rear-signaling systems to alert following drivers or provide additional cues regarding lead vehicle dynamics.

APPROACH

The approach used was to analyze the rear-end events in the 100-Car Study to evaluate hypotheses underlying the role of rear signaling in crash prevention and to identify lighting system parameters of enhanced rear-signaling systems that might help reduce rear-end crashes in terms of number or severity.

DATA INCLUDED IN THE ANALYSES

There were 7,024 events coded as Conflict with Lead Vehicle (LV) or Conflict with Following Vehicle (FV), as shown in Table 1. Table 2 presents the same data in terms of percentage of the number of each type of event. These events include all Conflict with LV and Conflict with FV events recorded for all drivers. A distinction is made between primary drivers (those drivers who signed informed consent forms and for whom there are demographic data) and secondary drivers (those who were allowed to drive the vehicles by the primary drivers). Tables 3 and 4 present the distribution and percentage of events recorded for primary and secondary drivers. In some cases the driver type is unknown because the face video was malfunctioning or blurred. Crashes, near-crashes, and incidents are defined in Table 5.

Table 1. Distribution of Events Coded as *Conflict With Lead Vehicle* and *Conflict With Following Vehicle* by Severity

	Severity			
Nature of Event	**Crash**	**Near-crash**	**Incident**	**Total**
Conflict with a following vehicle	12	70	764	846
Conflict with a lead vehicle	15	380	5,783	6,178
Total	27	450	6,547	7,024

Table 2. Percentage of Events Coded as *Conflict With Lead Vehicle* and *Conflict With Following Vehicle* by Severity

Nature of Event	Severity			
	Crash	Near-Crash	Incident	Total
Conflict with a following vehicle	44.4%	15.6%	11.7%	12.0%
Conflict with a lead vehicle	55.6%	84.4%	88.3%	88.0%
Total	100.0%	100.0%	100.0%	100.0%

Table 3. Distribution of *Conflict With Lead Vehicle* and *Conflict With Following Vehicle* Events by Driver Type and Severity

Driver Type	Severity			
	Crash	Near-Crash	Incident	Total
Primary	24	412	5,966	6,402
Secondary	3	38	576	617
Unknown	0	0	5	5
Total	27	450	6,547	7,024

Table 4. Percentage of *Conflict With Lead Vehicle* and *Conflict With Following Vehicle* Events by Driver Type and Severity

Driver Type	Severity			
	Crash	Near-Crash	Incident	Total
Primary	88.9%	91.6%	91.1%	91.1%
Secondary	11.1%	8.4%	8.8%	8.8%
Unknown	0.0%	0.0%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%

Table 5. Severity levels for the 100-Car Study. These are collectively known as "events"

Crash	Any contact with an object, either moving or fixed, at any speed, in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, or animals.
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. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle's capabilities. As a guide, subject-vehicle braking greater than 0.5*g* or steering input that results in a lateral acceleration greater than 0.4*g* to avoid a crash constitutes a rapid maneuver.
Incident	Any circumstance that requires a crash-avoidance response on the part of the subject vehicle or any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a "normal maneuver" to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal maneuver" for the subject vehicle is defined as a control input that falls outside of the 99-percent confidence limit for control input as measured for the same subject. Also includes cases resulting in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object when, due to apparent unawareness on the part of the driver, pedestrians, cyclists, or animals, there is no avoidance maneuver or response. Extraordinarily close proximity is defined as a clear case in which the absence of an avoidance maneuver or response is inappropriate for the driving circumstances (e.g., speed, sight, distance, etc.).

Note in Tables 1 and 2 that there were fewer following-vehicle events compared to lead-vehicle events in this data set. This was a result of differences in the radar signatures for a forward versus a rear-facing radar system. Essentially, a forward-facing radar system has more objects to discern since any static object the vehicle is approaching represents a potential threat. Alternatively, a rear-facing radar system only needs to produce a signature for objects moving toward the vehicle since all other targets are increasing in range as the vehicle moves forward. Therefore, there were more forward targets triggered in the dataset, and more forward events were validated.

In addition to there being a greater number of forward targets, it was easier to validate triggers for a lead-vehicle scenario versus a following-vehicle scenario. The radar units used in the study were designed to capture forward threats. The processing of targets was accomplished internally to the radar unit, using algorithms optimized for the forward-target case. For lead-vehicle conflicts, the radar signatures thus gave reductionists better data for the rate of deceleration, forward time-to-collision (TTC), and forward range, which could be verified readily using the subject vehicle accelerometer and the forward camera. However, the rear radar did not supply a direct measure of rate of deceleration or speed. For following-vehicle conflicts, the rate of deceleration was much harder to calculate and more difficult to assess by the reductionist with the rear-facing camera. Therefore, verifying conflicts with following vehicles was a more difficult process and only the most severe events were likely to be validated.

Chapters 9-12 (Goals 5-8) of the 100-Car Study (Dingus et al., 2005) provide detailed information on driver age and gender, kinematics characteristics, distractions, eye-glance behavior, driver response, and the relationships between incidents, crashes, and near-crashes for rear-end events. Chapters 9 and 10 of the 100-Car report (including only primary drivers) showed that 100 percent of the crashes in which the subject vehicle stuck a lead vehicle occurred when the lead vehicle was stopped. However, only 46 percent of lead-vehicle incidents and 43 percent of lead-vehicle near-crashes occurred when the lead vehicle was stopped (for lead-vehicle decelerating, it was 51 percent for incidents and 55 percent for near-crashes). In comparison, only 60 of the crashes in which the subject vehicle was struck by a following vehicle occurred when the subject (lead) vehicle was stopped. For this same scenario, 33 percent of incidents and 36 percent of near-crashes occurred with a stopped subject vehicle, while 61 percent for incidents and 62 percent for near-crashes occurred when the subject lead vehicle was decelerating. This indicates that the stopped-lead-vehicle scenario is much more likely to result in a crash, as opposed to the lead vehicle decelerating, moving at a slower constant speed, or accelerating scenarios.

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QUESTION 1: RESPONSE TIME AND BRAKING PATTERNS

What was the distribution of response time of the "following" driver to the lead-vehicle brake application? What is the relationship between response time, deceleration, and braking behavior of "following" drivers to the onset of the brake lamps of the lead vehicle? These data may help to provide an indication of real-world reaction times and the braking patterns of drivers.

Crash data provide very limited opportunities upon which to examine these issues. This is because there were very few crashes involving conflicts with a *decelerating* lead vehicle; as discussed later in Question #3, nearly all rear-end crashes involved a stopped lead vehicle. Only 6 of the 27 rear-end crashes involved a following vehicle striking a decelerating lead vehicle; all 6 resulted from conflicts with a following vehicle. That is, the instrumented vehicle was struck from behind as it was decelerating. As a result, this analysis focuses on near-crashes and incidents in which the instrumented vehicle encountered a conflict with a decelerating lead vehicle.

BRAKE RESPONSE TIMES

The overwhelming majority of drivers responded to a decelerating lead vehicle by braking; 99 percent of drivers in near-crashes and 95 percent of drivers in incidents responded to a decelerating lead vehicle by braking. In contrast, 47 percent of crash-involved drivers failed to brake and/or steer in response to the imminent threat. Median driver brake-response times were 1.30 s for near-crash events and 1.0 s for incidents. Figure 1 depicts the cumulative frequency distribution of driver brake-reaction times in response to a decelerating lead vehicle for near-crash and incident events. The response curves are somewhat similar; however, the distribution for incidents is offset slightly to the left, suggesting that drivers involved in incidents tended to have faster brake applications compared to drivers in near-crash events. Figure 2 provides a more detailed distribution of driver brake-response times for near-crash and incident events. There appears to be a marginal difference between near-crashes and incidents in terms of the percentage of drivers who responded immediately (within the first few moments) to the onset of the lead vehicle's brake lamps. Specifically, 25 percent of drivers in incidents had brake response times between 0.5 and 1.49 s, compared to 17 percent of drivers in near-crashes. These types of immediate responses may have made the difference between the event being classified as an incident rather than as a near-crash.

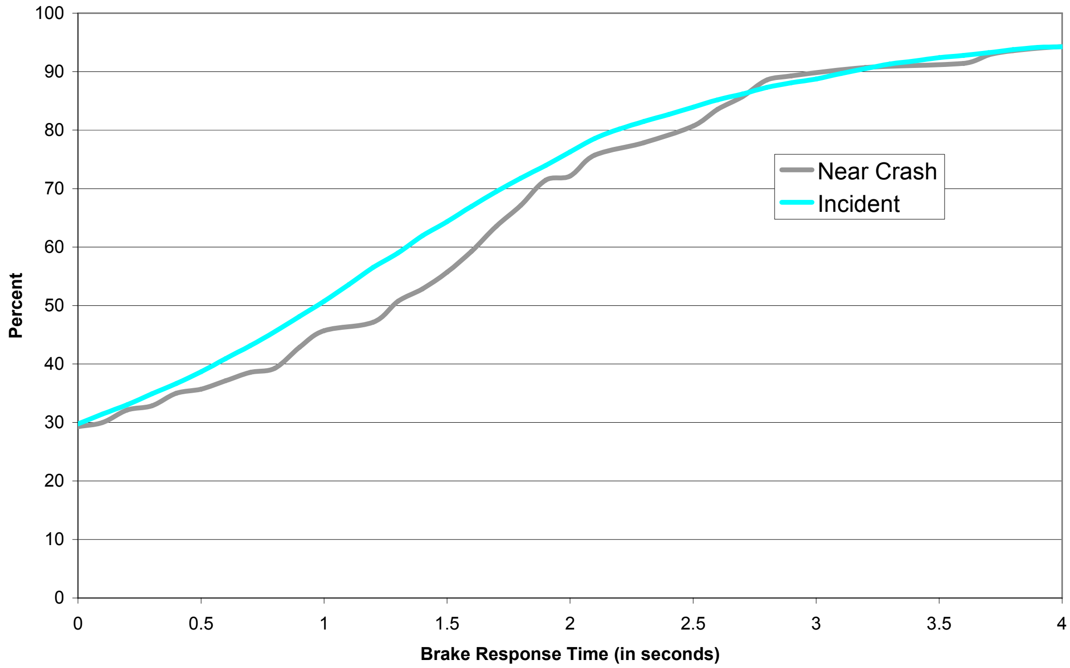

Figure 1. Cumulative distribution of brake-response times, conflicts with a decelerating lead vehicle (near-crashes & incidents).

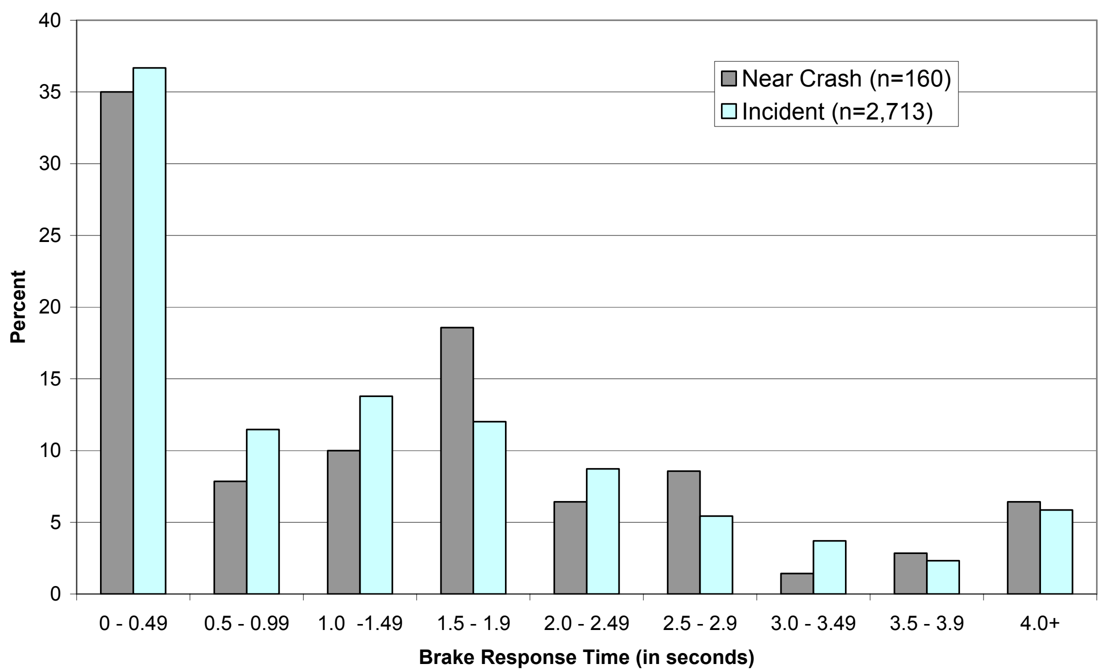

Figure 2. Brake response time categories, conflicts with a decelerating lead vehicle (near-crashes & incidents).

DECELERATION LEVELS

Only near-crash and incident data yielded relevant deceleration data for this question. Figure 3 presents the cumulative frequency distribution of peak deceleration for braking in response to a decelerating lead vehicle across both near-crashes and incidents. Higher peak decelerations were associated with near-crash events. Median peak deceleration was 0.74*g* for near-crashes and 0.52*g* for incidents. As shown in Figure 4, deceleration levels above 0.7*g* were almost exclusively associated with near-crash events; 58 percent of drivers in near-crashes had peak decelerations in excess of 0.7*g* compared to only 8 percent of incident-involved drivers. The averaged deceleration levels (average braking force over the duration of the braking event) were similar across near-crashes and incidents; median values were 0.19*g* for near-crashes and 0.16*g* for incidents.

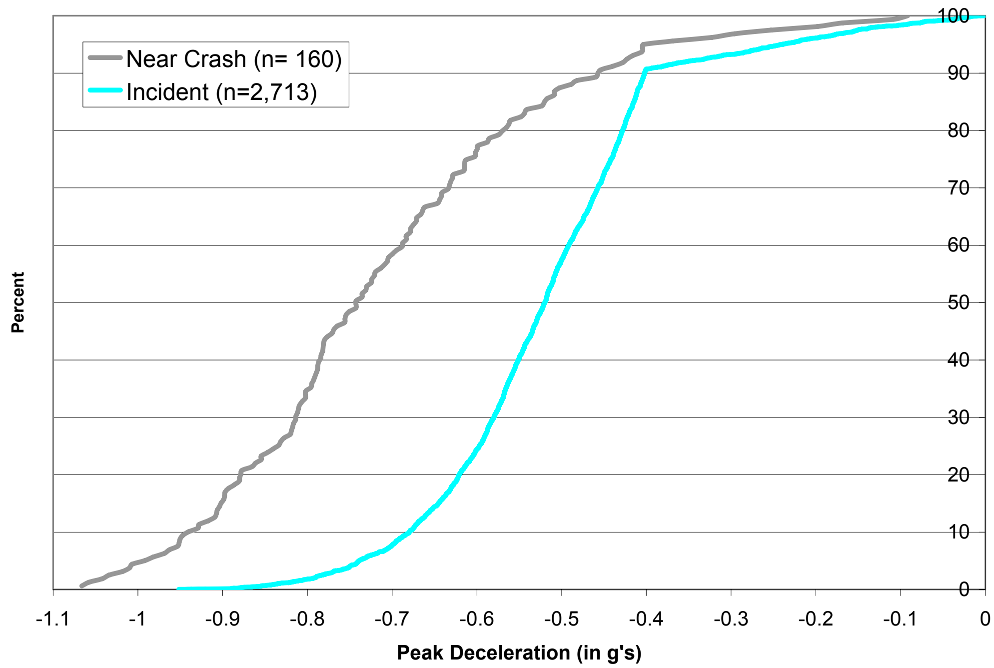

Figure 3. Cumulative distribution of peak deceleration, conflicts with a decelerating lead vehicle (near-crashes & incidents).

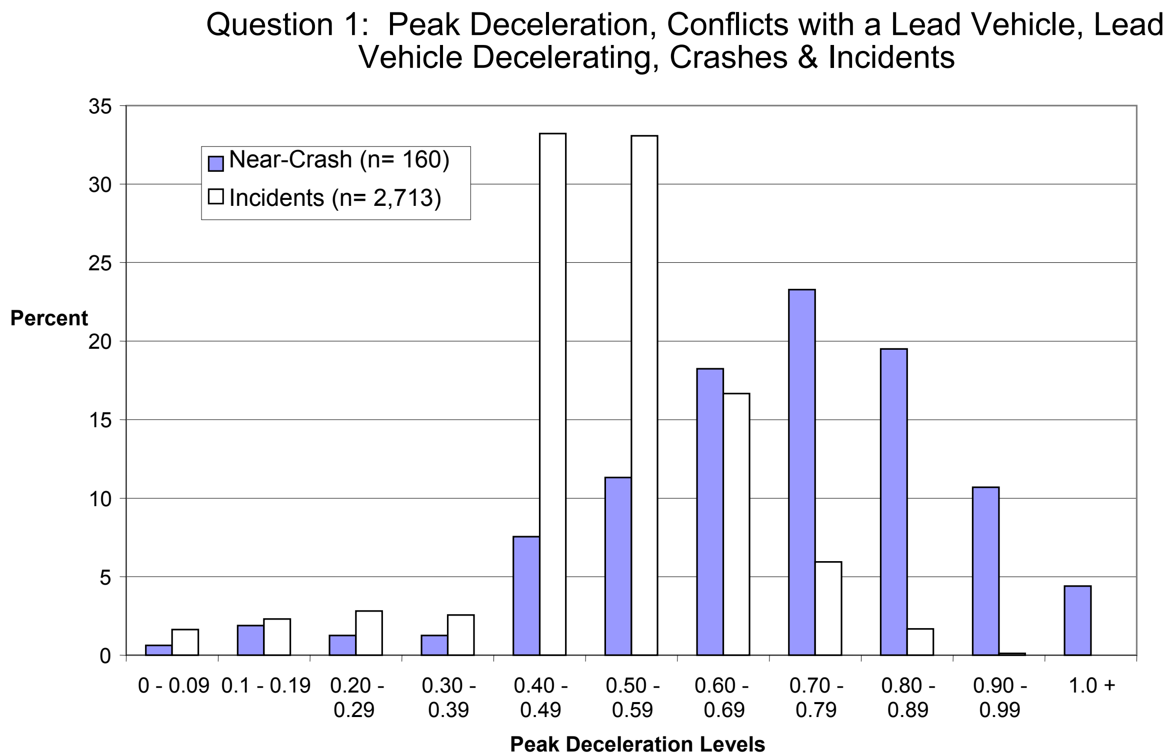

Figure 4. Peak deceleration categories, conflicts with a decelerating lead vehicle (near-crashes & incidents).

RELATIONSHIP BETWEEN RESPONSE TIME AND DECELERATION

As shown in Figure 5, no strong linear relationship was found between driver brake-response time and peak deceleration (r= -0.08). A marginal relationship was, however, found between braking response time and averaged deceleration (r = 0.24), suggesting that drivers with longer brake-response times also had higher sustained levels of deceleration (Figure 6).

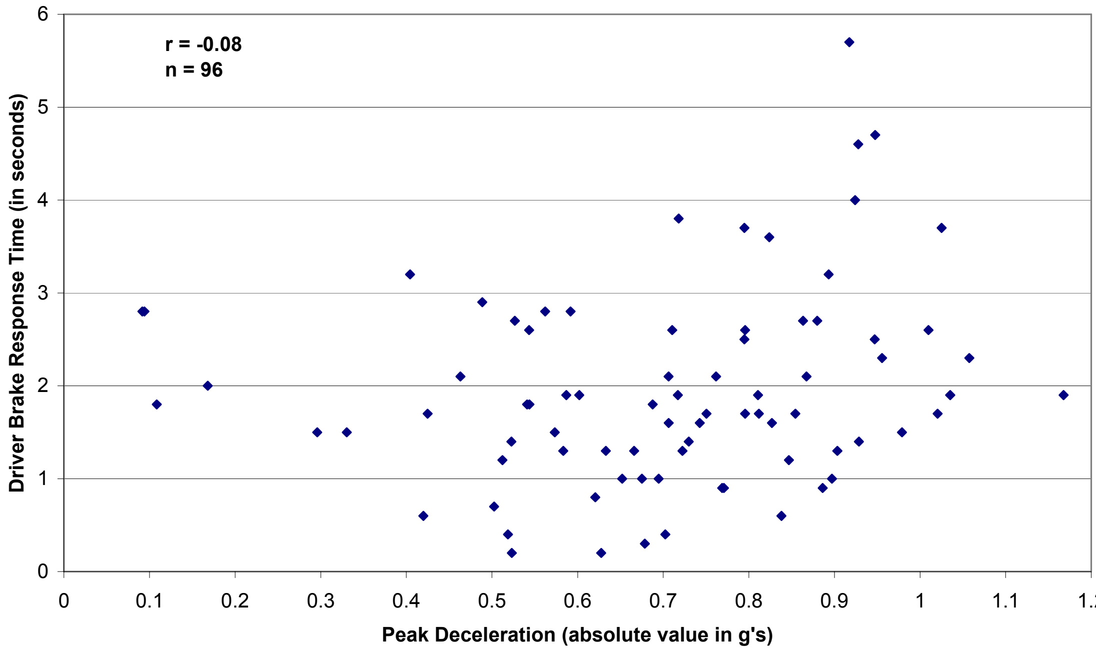

Figure 5. Scatterplot, brake-response time and peak deceleration, near-crashes, conflicts with a decelerating lead vehicle.

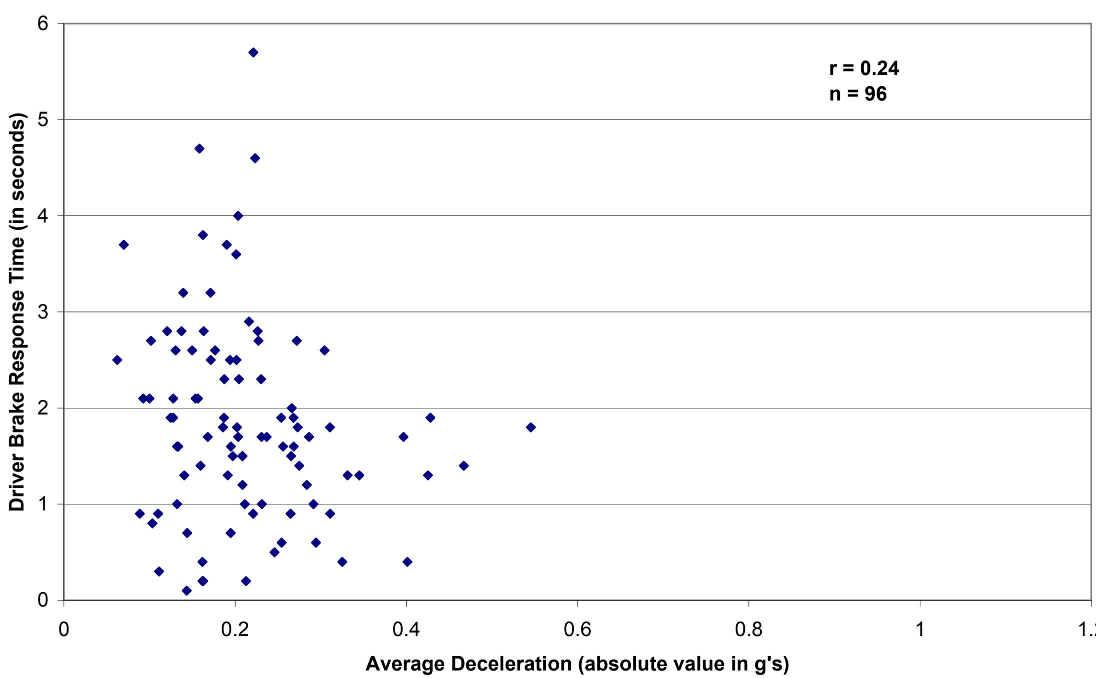

Figure 6. Scatterplot, brake-response time and average deceleration, near-crashes, conflicts with a decelerating lead vehicle.

BRAKE-RESPONSE TIME AND VISUAL DISTRACTION

The driver's visual fixation at the onset of lead vehicle braking was analyzed and related to brake-response time. Driver eye fixations were coded as either looking forward or not looking forward (many fixations were also not discernable from the video and therefore were coded as "unknown"). Only incidents were analyzed because near-crashes had too few instances of drivers not looking forward. Figure 7 plots the distribution of brake reaction time as a function of the driver's fixation point at the onset of lead-vehicle braking. Drivers whose focus of visual attention was not directly out the forward windshield (not forward) had substantially longer brake-reaction times compared to drivers whose eyes were directed forward at the time of lead-vehicle braking onset. The median brake reaction time for drivers looking forward was 1.0 s compared to 1.6 s for drivers not looking forward.

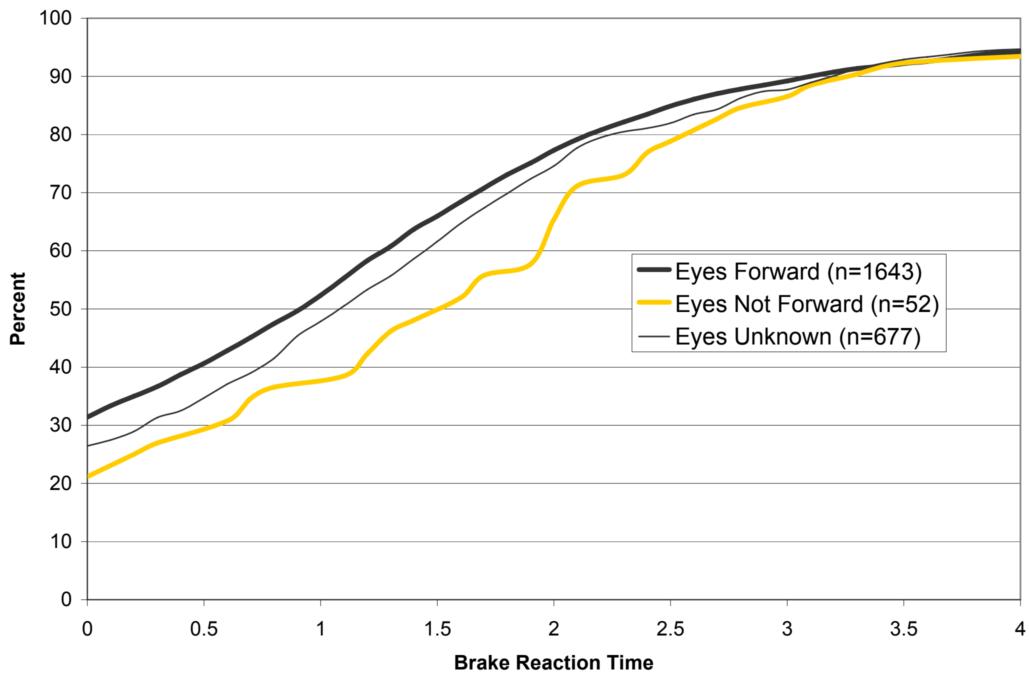

Figure 7. Distribution of brake-response times for incidents as a function of driver eye gaze at the onset of lead-vehicle braking (conflicts with a decelerating lead vehicle).

SUMMARY

Tables 6 and 7 present the summary statistics for the near-crashes and incidents analyzed for Question #1. In addition, the analysis supports the following conclusions:

- The distribution of brake-response times between near-crashes and incidents are not strikingly different, but there is evidence to suggest that drivers in incidents had faster brake response times than drivers in near-crashes. The advantage may be due to an immediate response within 1.5 s of the onset of the lead vehicle's brake lamps.
- Drivers who were glancing away from the forward roadway at the onset of lead-vehicle braking had substantially longer brake-response times (about 600 ms longer on average) compared to drivers whose visual focus was on the forward roadway.

Table 6. Percentile values for driver performance measures for near-crashes and incidents.

	N	Percentile Values 10th	25th	50th	75th	90th
Near Crash						
Brake Response Time (sec)	140	0.00	0.00	1.30	2.10	3.20
Peak Deceleration (g's)	159	-0.45	-0.60	-0.74	-0.83	-0.94
Average Deceleration (g)	159	-0.10	-0.14	-0.19	-0.25	-0.32
Braking Duration (sec)	133	1.30	2.00	3.30	5.30	8.70
Minimum TTC (sec)	127	0.31	0.53	0.82	1.28	2.29
Incident						
Brake Response Time (sec)	2,372	0.00	0.00	1.00	2.00	3.20
Peak Deceleration (g's)	2,694	-0.40	-0.44	-0.52	-0.59	-0.68
Average Deceleration (g)	2,694	-0.09	-0.13	-0.16	-0.20	-0.25
Braking Duration (sec)	2,128	1.40	2.50	4.00	6.30	9.00
Minimum TTC (sec)	2,334	0.78	1.04	1.35	1.78	2.40

Table 7. Driver performance mean values for various brake-response time categories for near-crashes and incidents.

	Near Crash						Incidents				
Brake Response Time	N	Peak Decel	Average Decel	Brake Duation	Minimum TTC		N	Peak Decel	Average Decel	Brake Duation	Minimum TTC
0.0 - 0.49	49	-0.71	-0.21	4.58	0.94		870	-0.51	-0.18	5.1	1.54
0.5 - 0.99	11	-0.67	-0.20	3.75	0.87		272	-0.53	-0.17	4.55	1.48
1.0 - 1.49	14	-0.76	-0.26	4.02	1.06		327	-0.53	-0.16	4.53	1.52
1.5 - 1.99	26	-0.76	-0.24	4.48	1.57		285	-0.52	-0.17	4.47	1.53
2.0 - 2.49	9	-0.69	-0.16	4.15	0.70		207	-0.53	-0.16	4.34	1.43
2.5 - 2.99	16	-0.67	-0.17	4.09	1.42		129	-0.53	-0.15	4.71	1.55
3.0 - 3.49	2	-0.96	-0.15	4.05	3.79		88	-0.53	-0.16	4.85	1.4
3.5 - 3.99	4	-0.65	-0.15	2.47	0.71		55	-0.53	-0.15	4.87	1.61
4.0 +	9	-0.64	-0.14	3.77	0.74		138	-0.45	-0.13	4.41	1.62
	140	-0.71	-0.20	4.23	1.12		2371	-0.51	-0.17	4.74	1.52

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QUESTION 2: FOLLOWING-VEHICLE DRIVER DISTRACTION

To what extent were "following" drivers distracted and thus did not see the lead vehicle braking? What was the focus of visual attention of the "following" driver (e.g., mirror, inside object, passenger, etc.)?

Driver distraction is believed to be a factor in a substantial percentage of collisions. Research suggests that somewhere between 10 to 50 percent of collisions may be distraction-related (NHTSA, 1997; Stutts et al., 2001). This analysis examines the role of distraction in rear-end crashes, near-crashes, and incidents for 100-Car Study drivers. Analyses are limited to rear-end events (crashes, near-crashes, and incidents) in which the instrumented vehicle struck or had a conflict with the lead vehicle (e.g., conflicts with a lead vehicle); these situations represent about 88 percent of the observed rear-end conflict events.

Of the 6,177 rear-end conflicts with a lead vehicle, 26 percent involved a distracted driver. As shown in Figure 8, although driver distraction appears to be an important factor across all types of rear-end conflicts, its contribution to crashes is significant. Approximately 87 percent of rear-end crashes in which the driver struck the lead vehicle included some form or degree of driver distraction, which is much higher than the rates of distraction observed for near-crashes and incidents (refer to Table 8). Moreover, 47 percent of crash-involved drivers were observed to have no discernable crash-avoidance response (e.g., braking, steering, etc.), suggesting that drivers were not aware of the evolving and imminent crash situation because they were not paying attention or were distracted.

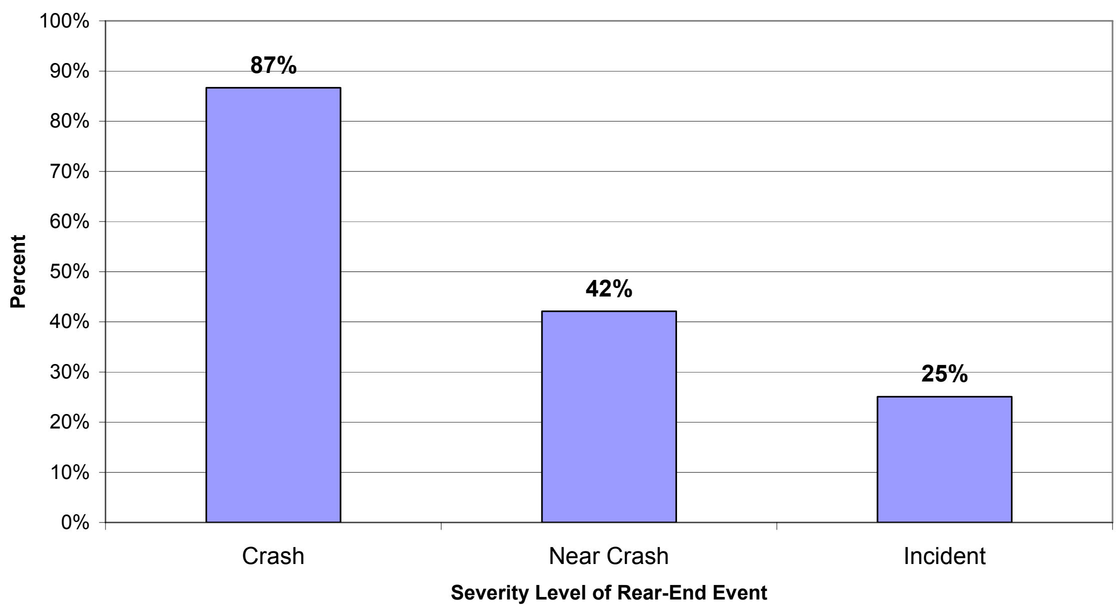

Figure 8. Percent of Rear-End Conflicts Involving Driver Distraction (Limited to Following-Driver Conflicts with Lead Vehicle; 15 Crashes, 380 Near-Crashes, and 5,783 Incidents).

Table 8. Rear-End Lead-Vehicle Conflicts Involving Distracted/Not Distracted Drivers.

	Severity Level of Rear End Event			
	Crash	**Near-crash**	**Incident**	**Total**
Distracted	13 87%	160 42%	1,450 25%	1,623 26%
Not Distracted	1 7%	216 57%	4,327 75%	4,544 74%
No Data	1 7%	4 1%	5 <1%	10 <1%
Total	15	380	5,782	6,177

Drivers were found to be engaged in a variety of secondary tasks during the onset of the rear-end event – some related to the driving task itself. Over 60 specific activities were defined across 11 activity categories (refer to Table 9). Figure 9 illustrates the rate of involvement across different distraction tasks for crashes, near-crashes, and incidents. Although no single set of activities universally accounted for the majority of distraction events, driving-related inattention (e.g., checking mirrors, looking out windows, etc.), and to a lesser degree internal distraction (e.g., reaching for an object, pet in vehicle, etc.), accounted for a substantial percentage of distraction across crashes, near-crashes and incidents. These two activities alone were present in 39 percent of distraction-related crashes, 41 percent of near-crashes, and 22 percent of incidents. In general, the observed rate of involvement in distraction tasks varied based on the level of severity of the event. For example, use of wireless devices (e.g., cell phone) had a substantial impact on the frequency of near-crashes and incidents, but not crashes. No crash-involved drivers were observed to be using a wireless device at the time of the event, while over 22 percent of near-crashes and 31 percent of incidents involved a driver who was using a wireless device. Conversing on a cell phone (e.g., talking/listening) far outpaced any other cell-phone related tasks including dialing, answering, or searching for the cell phone.

Table 9. Sources of Driver Distraction for Rear-End Conflicts with a Lead Vehicle.

Distraction Categories	Level of Severity		
	Crash	Near-Crash	Incident
Passenger-Related	**0.00%**	**8.13%**	**13.38%**
Passenger in adjacent seat		7.50%	11.59%
Passenger in rear seat			1.17%
Child in adjacent seat			0.07%
Child in rear seat		0.63%	0.55%
Talking/Singing	**0.00%**	**3.75%**	**4.21%**
Talking/Singing/Dancing		3.75%	4.21%
Internal Distraction	**7.69%**	**11.88%**	**7.79%**
Reading		1.88%	2.07%
Moving object in vehicle		1.25%	0.48%
Object dropped by driver			0.07%
Reaching for object		3.75%	2.83%
Insect in vehicle			0.14%
Pet in vehicle	7.69%	5.00%	2.21%
Wireless Device	**0.00%**	**22.50%**	**31.17%**
Talking/Listening		13.13%	24.28%
Head-set on conversation			
Dialing hand-held cell phone		6.25%	4.28%
Dialing hand-held cell phone using quick keys			0.21%
Dialing hands-free using voice activated			0.41%
Locating/reaching/answering cell phone		0.63%	0.69%
Cell phone other		1.88%	1.10%
Locating/reaching PDA			
Operating PDA		0.63%	0.14%
Viewing PDA			0.07%
Vehicle Related Secondary Task	**7.69%**	**3.75%**	**7.38%**
Adjusting climate control			0.69%
Adjusting radio		3.75%	5.24%
Inserting/retrieving cassette			0.07%
Inserting/retrieving CD			0.07%
Adjusting other device integral to vehicle			0.34%
Adjusting other known in-vehicle devices	7.69%		0.97%
Dining	**15.38%**	**5.00%**	**6.14%**
Eating with utensil			0.34%
Eating without utensil	7.69%	4.38%	3.72%
Drinking with covered/straw			1.10%
Drinking out of open cup	7.69%	0.63%	0.97%

Distraction Categories	Level of Severity		
	Crash	Near-Crash	Incident
Smoking	**0.00%**	**0.00%**	**1.86%**
Reaching for cigar cigarette			0.14%
Lighting cigar/cigarette			0.07%
Smoking cigar/cigarette			1.66%
Extinguishing cigar/cigarette			
Daydreaming	**15.38%**	**5.00%**	**2.00%**
Lost in thought	7.69%	2.50%	0.28%
Looked but did not see		1.25%	0.28%
Cognitive - Other	7.69%	1.25%	1.45%
External Distraction	**0.00%**	**5.63%**	**4.62%**
Looking at previous crash or highway incident		0.63%	0.07%
Pedestrian located outside vehicle			0.14%
Animal located outside the vehicle			
Object located outside the vehicle			0.14%
Construction zone			
Other external distraction		5.00%	4.28%
Personal Hygiene	**0.00%**	**5.00%**	**7.17%**
Combing/brushing/fixing hair			1.52%
Applying make-up		1.88%	1.66%
Shaving			
Brushing/flossing teeth			0.07%
Biting nails			0.62%
Removing jewelry			
Removing /inserting contacts			0.41%
Other		3.13%	2.90%
Driving Related Inattention to Forward Roadway	**30.77%**	**29.38%**	**14.28%**
Checking center rear-view mirror		7.50%	3.45%
Looking out left side of windshield			
Looking out right side of windshield			
Checking left rear-view mirror	7.69%	3.75%	0.97%
Looking out left window	23.08%	11.25%	5.45%
Checking right rear-view mirror		0.63%	0.21%
Looking out right window		6.25%	4.21%
Looking at instrument panel			
No Data	1	4	5
Not Distracted	1	216	4,327
Total N	15	380	5,782

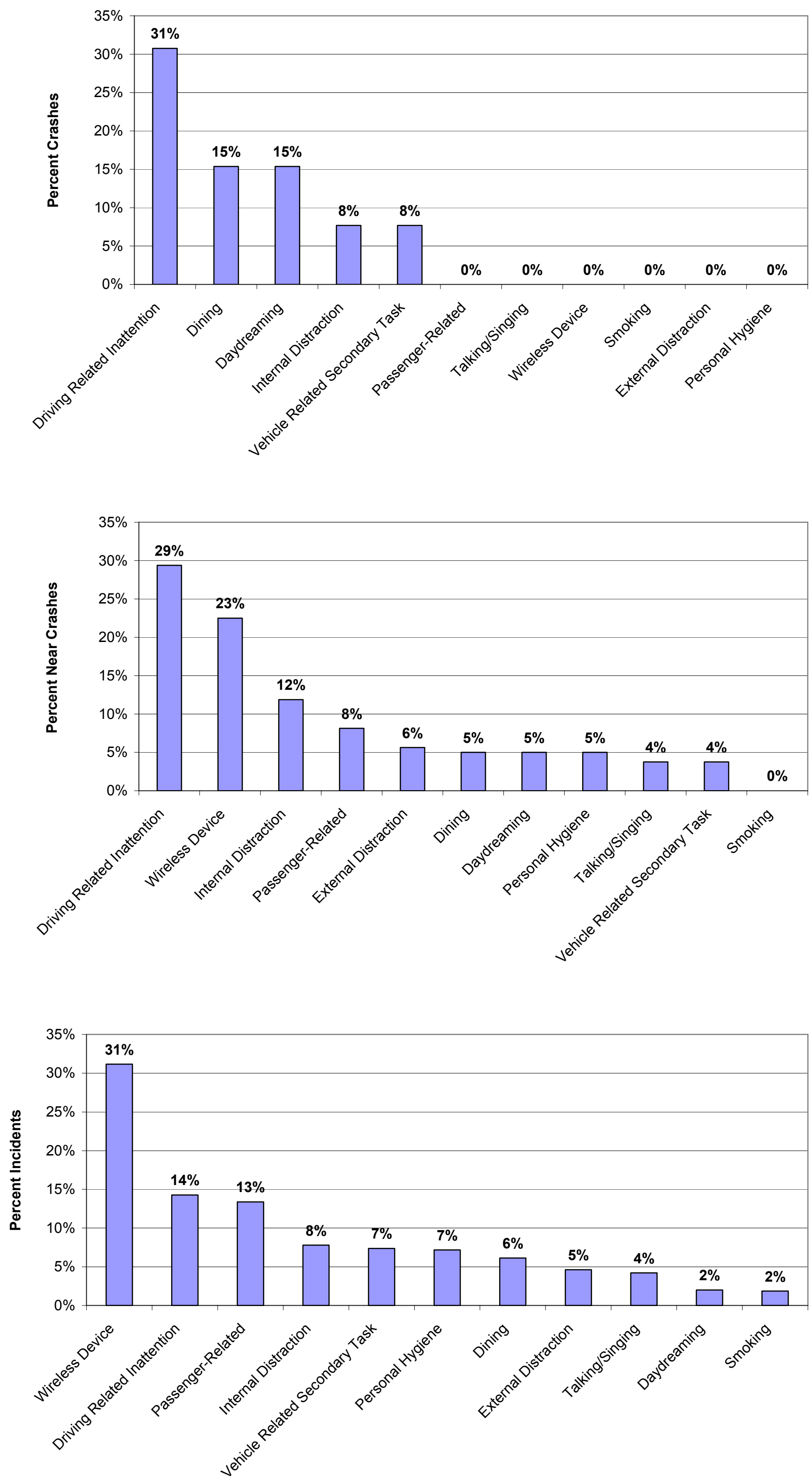

Figure 9. Types of Observed Driver Distraction for Rear-End Lead-Vehicle Conflicts. Percentage of Distractions Associated with Crashes (Top Panel), Near-Crashes (Middle Panel), and Incidents (Bottom Panel).

Interestingly, the types of distraction-related activities observed here for rear-end crashes were very different than for the general types of crashes reported by the AAA Foundation for Traffic Safety in an analysis of NASS CDS police-reported crashes (see Table 10; Stutts, Reinfurt, Staplin, & Rogman, 2001). The observational method used as part of the 100-Car Study clearly allowed for a more detailed analysis and accounting of distraction related tasks than that afforded by archived crash records.

Table 10. Comparison of Top Ranking Distraction Activities

AAA FTS Distraction Categories	Crashes, AAA	100-Car Data (Rear-End Conflicts)		
		Crash	**Near-Crash**	**Incident**
Outside Person, Object or Event	29.4%	0.0%	5.6%	4.6%
Adjusting Radio/Cassette/CD	11.4%	0.0%	3.8%	5.4%
Other Occupant	10.9%	0.0%	8.1%	13.4%
Moving Object in Vehicle	4.3%	7.7%	7.5%	11.6%
Other Device/Object	2.9%	0.0%	3.8%	2.9%
Adjusting Vehicle/Climate Controls	2.8%	7.7%	0.0%	2.0%
Eating and/or Drinking	1.7%	15.4%	5.0%	6.1%
Using/Dialing Cell Phone	1.5%	0.0%	21.9%	31.0%
Smoking Related	0.9%	0.0%	0.0%	1.9%
Other Distractions	25.6%	61.5%	41.9%	20.8%
Unknown Distraction	8.6%	7.7%	2.5%	0.3%

Data presented later in Question 5 also show that the vehicle profiles preceding the critical rear-end event were very similar across crashes, near-crashes, and incidents. For example, following headways sampled 3 s prior to the event averaged 1.92, 1.65, and 1.87 s for crashes, near-crashes, and incidents, respectively. This suggests that crash-involved drivers were not necessarily more aggressive than non-crash-involved drivers and that the key distinction may be with respect to differences in the driver's allocation of visual attention immediately preceding the event.

ALLOCATION OF VISUAL ATTENTION

As illustrated in Figure 10, there is a distinct difference across the distribution of eyes-off-road (EOR) time for drivers involved in crashes compared to near-crashes and incidents. The mean EOR time for crashes, near-crashes, and incidents is 3.01, 0.98, and 0.90 s, respectively. Glances away from the roadway of more than 2 s are much more common in crashes than in either of the two other event types. Specifically, approximately 64 percent of crash-involved drivers had EOR times > 2 s compared to approximately 15 percent and 13 percent of near-crash- and incident-involved drivers, respectively. Table 11 identifies the driver's point of gaze at the onset of the lead vehicle's brake lamps across crashes, near-crashes, and incidents. The gaze location is described in terms of degrees Up and Down and Left and Right (so 10D/30R = 10 degrees downward and 30 degrees to the right). Vehicles differ in their design, so in this table, it is not possible to say exactly what they were looking at for each of the gaze locations (for example, the radio may be in quite different locations in different vehicles). Surprisingly, many crash-involved drivers (40%) were looking out the front windshield ahead at time of lead-vehicle braking onset. Only about 13 percent of crash-involved drivers were looking down in the cab near the center console area (75D & 90D).

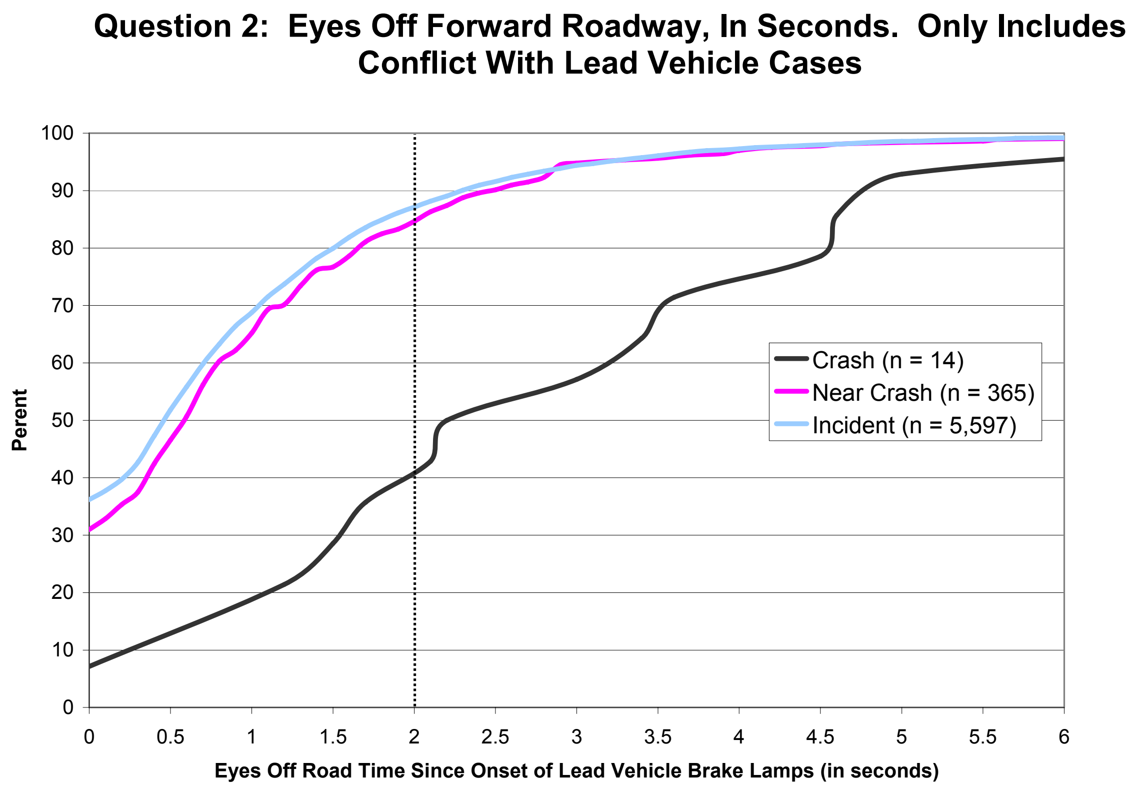

Figure 10. Distribution of Driver EOR Times (in Seconds) Since Onset of Lead-Vehicle Brake Lamps. Only Includes Conflict With Lead Vehicle Cases

Table 11. Drive Gaze Point at Onset of Lead Vehicle Braking (Onset of Brake Lamp). Cells Represent Percentages. The gaze location refers to degrees Up and Down and Left and Right. N/A refers to data that are unavailable or of poor quality.

Gaze Location (at Onset of Lead Vehicle Brake		Level of Severity (Conflict with a Decelerating Lead Vehicle)		
		Crash* (n=15)	Near Crash (n=160)	Incident (n=2713)
0/0	Direct Out	40.00	70.63	68.49
0/20R				
0/90R				0.04
10D/30R				0.04
10U/0				0.07
10U/10R				0.04
20D/0				.
20D/10R				.
20D/13L				.
20D/15R				0.04
20D/30R				0.04
20U/0				.
25D/0			0.63	0.11
25D/10L				.
25D/10R				.
25D/15L				0.04
25D/15R				0.07
25D/5L				0.04
30D/0				0.18
30D/10L			.	0.04
30D/15L				0.04
30D/15R			0.63	0.11
30D/30R			0.63	0.74
35D/0				.
35D/15L				0.04
35D/5R				.
40D/0			.	0.11
40D/15R				.
40D/30R				0.15
40D/5L				0.04
40D/5R				0.04
40D/60R				.
55D/30R				0.04
75D/30R			.	0.04
75D/40R		6.67		0.04
75D/45R				0.04
80D/0				.
80D/30R				0.04
90D/0		6.67	.	0.11
90D/30R			.	0.04
90D/55R				0.04
90D/5L				.
90D/5R				0.04
90D/20L			0.63	
N/A		46.67	26.88	29.16
	Total	100	100	100

* Conficts with lead vehicles, includes decelerating and stopped.

The findings in Table 11 were compared to the Task 2, Experiment 2 findings from the original Enhanced Rear Lighting and Signaling project (Wierwille, Lee, & DeHart, 2003) to see whether any of the crashes, near-crashes, or incidents could have been affected by a light system that is more visible in the peripheral visual zones. Note that virtually none of the crashes, near-crashes, or incidents represented failures of horizontal peripheral detection (0D/20R and 0D/90R, with the numbers representing degrees of glance and the letters representing direction in terms of up/down and left/right). For diagonal peripheral detection (those in which the driver was looking both down and to the right or left), there is an indication that the Traffic Clearing Lamp (TCL) could have helped in the 7 percent of crashes with a glance location of 75D/40R, but probably not in the 7 percent with a glance location of 90D/0R. The Alternating Pair (AP) would not have been likely to help in any of these cases. In the 2 percent of near-crashes occurring with various diagonal glance angles, the angles were shallow enough that either the TCL or the AP might have drawn the driver's gaze forward. For incidents, either the TCL or the AP might have drawn the driver's gaze forward for all cases involving diagonal angles up to 55D/30R, while the TCL might have also been beneficial for those cases with 75D angles (75D/30R, 75D/40R, and 75D/45R). Altogether, these cases represent about 2 percent of incidents. Fewer than 1 percent of incidents had greater peripheral angles than these, and none of the lights tested in the original study would have helped in these cases.

In a study of driver eyeglance behavior during car-following, Tijerina, Barickman, and Mazzae (2004) found that drivers tend to glance away under the following two conditions: as the duration of the car-following epoch increases, and when the optical expansion rate is zero. Drivers appear to be following a strategy based upon the expectation that the lead vehicle will not brake hard (based on immediate experience). The 100-Car data found instances where the following driver seemingly looked away as or right after the lead vehicle started braking (and the lead vehicle's lights were activated). The Tijerina et al. (2004) results could explain why drivers did this. In many cases, the lead vehicle had been lightly applying the brakes for some period of time before suddenly applying them with more force.

Tijerina also found that shorter glance durations (mean of 0.6s) for these baseline car-following events; by comparison, the current analysis found mean glance durations of 0.90, 0.98, and 3.01s for incidents, near-crashes and crashes. The major difference is that the 100-Car dataset was comprised of critical events (non-baseline events), whereas Tijerina et al. was based on "normative" (i.e., baseline) driving situations. These finding reinforce the basic argument that drivers get lulled into the false expectation that the lead vehicle will not change the driving situation by suddenly braking hard.

SUMMARY

- Drivers are routinely engaged in activities while driving that divert their attention from the forward roadway. Executing driving-related activities themselves (e.g., scanning the mirrors) appear to be a significant and common source of driver distraction.
- Different patterns of distraction inducing activities emerged for crashes, near-crashes and incidents. Dining and daydreaming were strongly associated with crashes. Use of wireless devices (and cells phones in particular) contributed to near-crashes and incidents, as did passenger-related distraction.

- Cell phone use, and in particular conversing (talking/listening) on a cell phone while driving, was among the top distraction-causing activities contributing to near-crashes and incidents.
- Cognitive distraction appears to be a common underlying theme; this category could include cell-phone conversation, looked but did not see, and daydreaming.
- These analyses do not take into account the relative rate of exposure – just the raw counts.
- Driver gazes to the forward roadway (front windshield) do not guarantee that drivers are attentive and processing relevant cues. Approximately 40 percent of crash-involved drivers had their gaze directed out the front windshield at the time of lead-vehicle braking onset. However, once the lead-vehicle brake lamps were visible, crash-involved drivers proceeded to look away from the forward view for longer periods of time than incident- and near-crash-involved drivers. This makes a strong argument that additional salient cues may be needed to alert drivers to the onset of lead-vehicle braking events.
- In cases where the driver's eyes were off the forward view at the time the lead-vehicle brake lamps came on, there is evidence from previous studies that certain lamp types might have drawn the driver's eyes forward more quickly.

QUESTION 3: FOLLOWING TOO CLOSE

To what extent were "following" drivers so close that they simply could not "outbrake" the lead vehicle? Were lead vehicles decelerating too quickly for the "following" vehicle to stop given the headway and speed prior to lead-vehicle braking?

The majority of rear-end crash events (59%, or 16 out of 27) involved a stopped lead vehicle; only 22 percent (6 out of 27) rear-end crashes occurred under conditions of a decelerating lead vehicle. As shown in Figure 11, all six cases involved a conflict with a following vehicle in which the instrumented vehicle (subject vehicle) was decelerating when it was struck from behind. Therefore, very limited crash data exist upon which to examine this question. However, near-crash and incident data provide additional opportunities to explore this question; approximately 41 percent (or 185 out of 450) of near-crashes involved a decelerating lead vehicle. The majority of these cases were conflicts with a lead vehicle in which the instrumented (or subject vehicle) nearly hit the lead vehicle it was following. As shown in Figure 11, approximately 42 percent of near-crash conflicts with a lead vehicle (160 out of 380) involved a decelerating lead vehicle, while approximately 36 percent of near-crash conflicts with a following vehicle (25 out of 70) involved a decelerating lead vehicle.

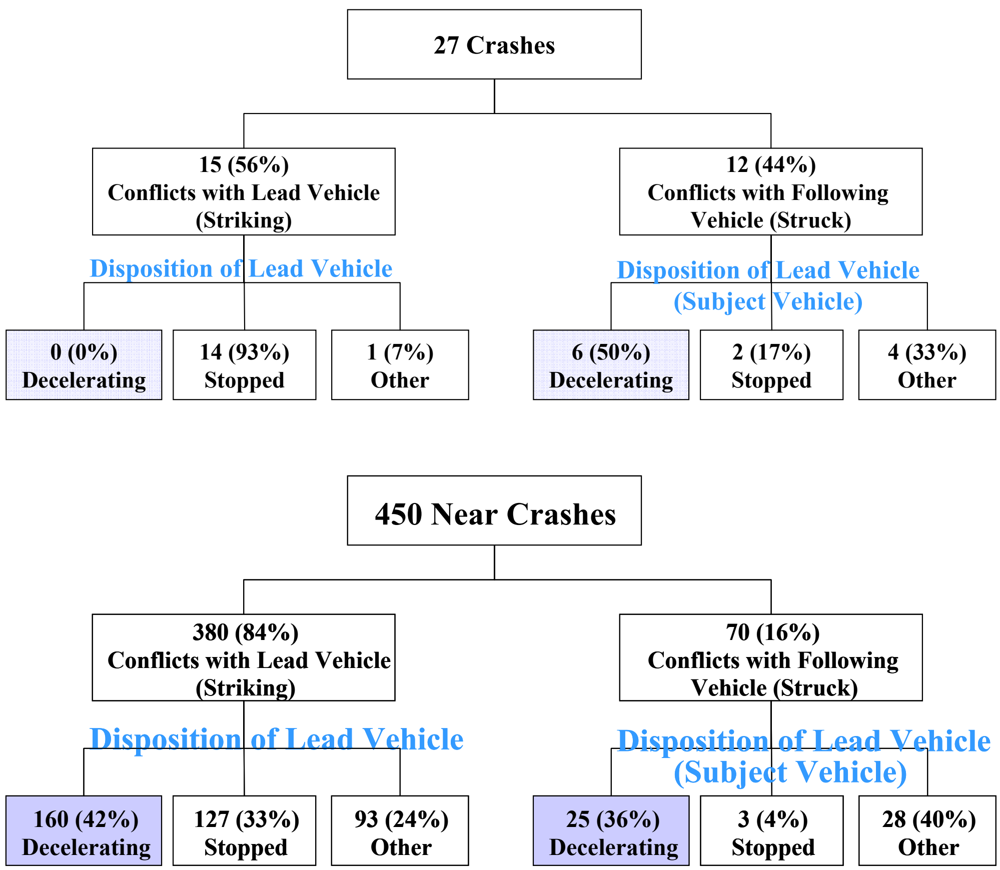

Figure 11. Rear End Conflicts, Crash & Near-Crash Events.

Vehicle headways and TTC values are presented in Figures 12 and 13 for the onset of lead-vehicle braking (indexed by the illumination of the lead vehicle's brake lamps) for near-crash and incident conflicts with a lead vehicle. The patterns across near-crash and incident events are very similar and suggest that the vast majority of drivers were not necessarily following too closely at the onset of lead-vehicle braking.

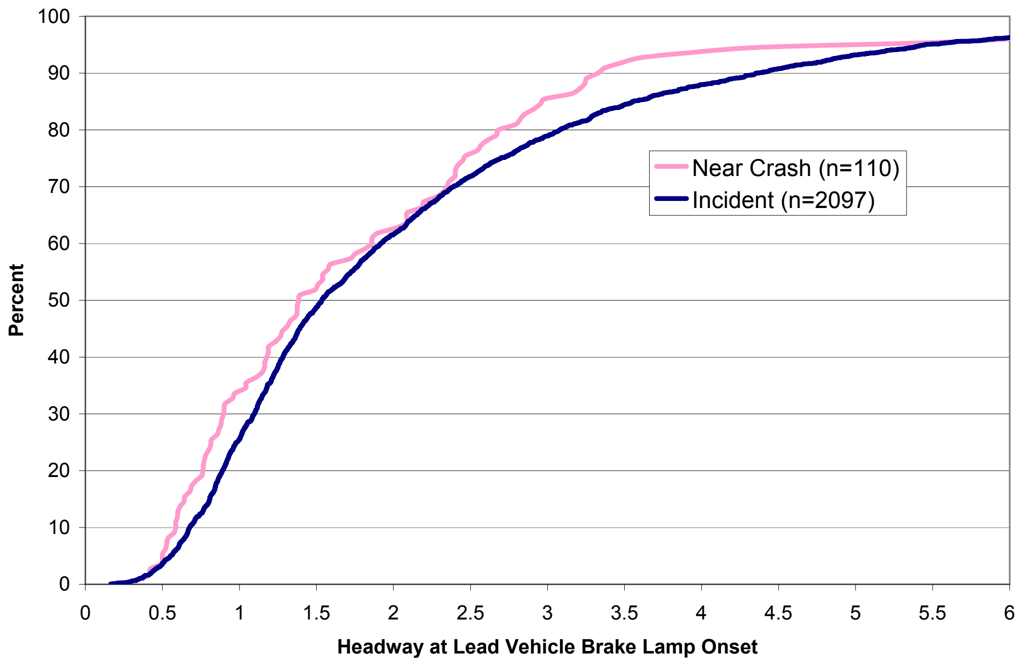

Figure 12. Time Headways (Seconds) at Onset of Lead-Vehicle Braking (Conflicts With a Lead Vehicle, Lead-Vehicle Decelerating Cases).

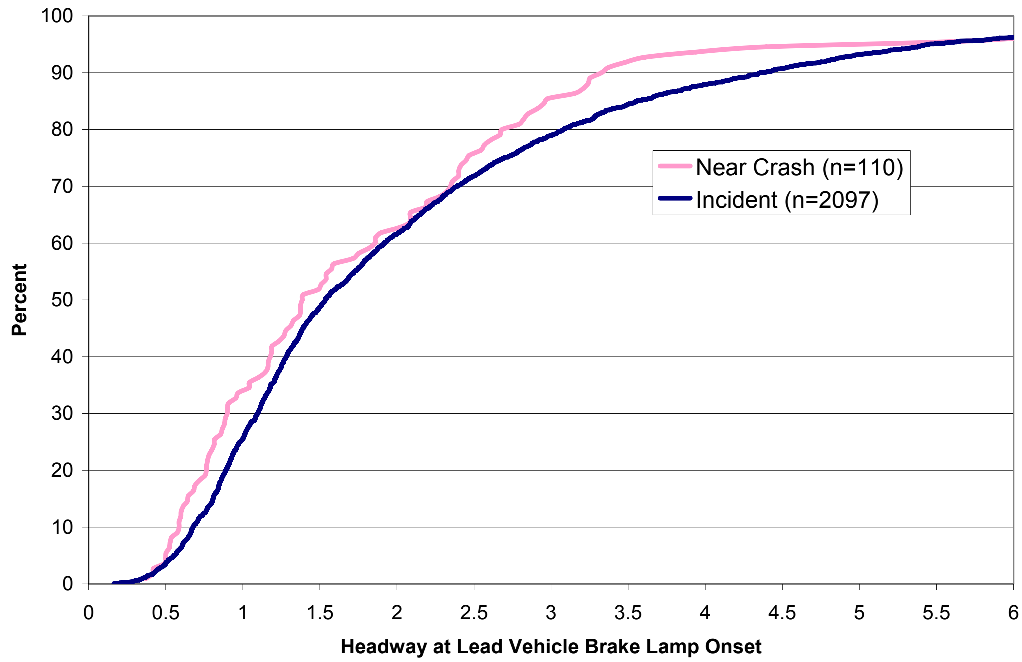

Figure 13. TTC (Seconds) at Onset of Lead-Vehicle Braking (Conflicts With a Lead Vehicle, Lead-Vehicle Decelerating Cases).

Although some drivers adopted short following distances (the 25th percentile values were less than 1 s for both near-crashes and incidents), TTC values were well above imminent crash levels (Table 12), suggesting that the following drivers were maintaining an acceptable distance from the lead vehicle given their speed at the onset of lead-vehicle braking.

Table 12. Percentile Distributions for Key Measures across Rear-End Near-Crash and Incident Events.

Values at Lead-Vehicle Braking Onset and During Event	Percentile Values, Conflict With Lead Vehicle, Lead-Vehicle Decelerating Cases					
Near-Crash	**N**	**10th**	**25th**	**50th**	**75th**	**90th**
Time-to-Collision (sec)	47	2.08	3.47	6.05	10.19	20.24
Headway (sec)	110	0.58	0.81	1.38	2.46	3.35
Peak Deceleration, Lead Vehicle (g)	23	0.23	0.41	0.47	0.57	0.68
Peak Deceleration, Following Vehicle (g)	159	0.43	0.60	0.74	0.83	0.94
Incident	**N**	**10th**	**25th**	**50th**	**75th**	**90th**
Time-to-Collision (sec)	769	2.31	3.93	6.45	12.04	23.28
Headway (sec)	2097	0.67	0.98	1.53	2.69	4.37
Peak Deceleration, Lead Vehicle (g)	191	0.17	0.31	0.43	0.51	0.61
Peak Deceleration, Following Vehicle (g)	2708	0.40	0.44	0.51	0.59	0.67
Values during Event	**Percentile Values, All Rear-End Events Combined (Crashes, Near-crashes, Incidents)**					
Peak Deceleration	**N**	**10th**	**25th**	**50th**	**75th**	**90th**
Lead Vehicle	612	0.11	0.22	0.42	0.52	0.62
Following Vehicle	4,800	0.33	0.43	0.51	0.59	0.69

LEAD-VEHICLE DECELERATION LEVELS

As shown in Figures 14 and 15, there is a clear distinction between the deceleration distributions depending on whether the conflict is with a lead or following vehicle. For example, Figure 14 presents the near-crash and incident peak deceleration distribution for the lead vehicle, in the case of a conflict with a following vehicle. The distributions are very similar, with the near-crash decelerations being slightly harder than the incident decelerations. Figure 15 presents the same type of information, except that now the conflict is with a lead vehicle and the distribution represents following vehicle deceleration. It can be seen that the deceleration levels are higher in this case, and that the near-crash and incident events are clearly separated. Taken together, these figures indicate that drivers are more responsive to events happening in the forward view than to events unfolding behind them. For example, they braked harder for more serious events occurring in the forward view (Figure 15). If they were aware of events unfolding behind them, they should brake more gently for serious events unfolding behind them (to lessen the possibility of a rear-end crash); as shown in Figure 14, this did not occur. However, given the percentage of time that drivers spend looking at the forward view as compared to the rear view, these findings make sense.

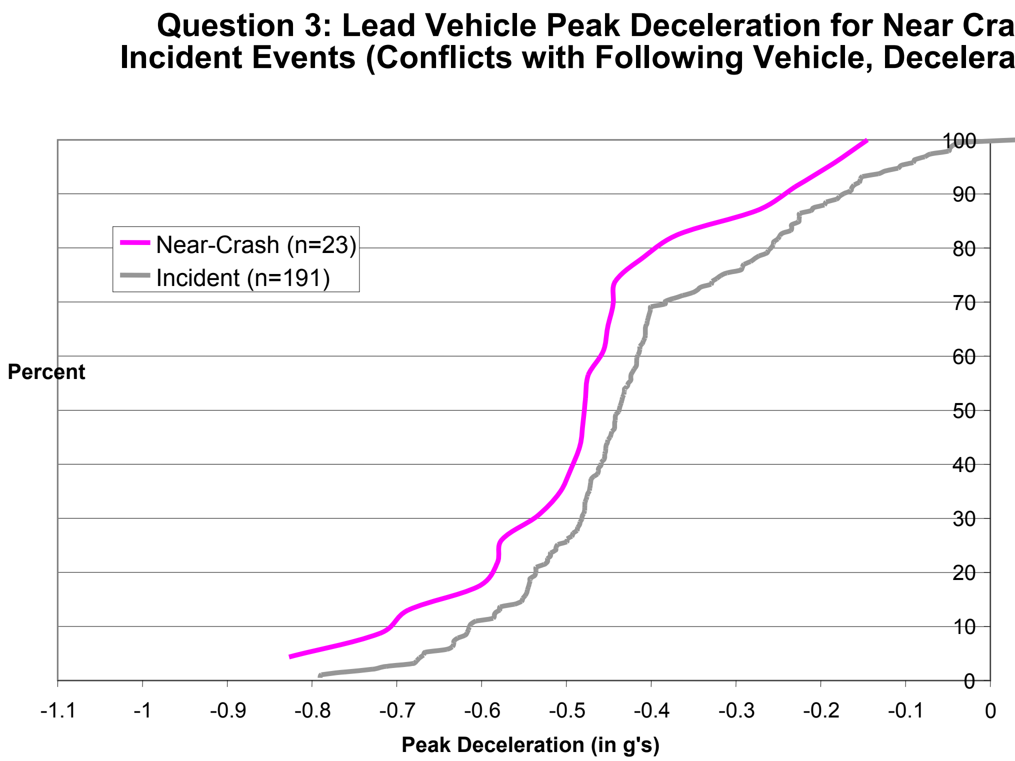

Figure 14. Lead-Vehicle Peak Deceleration, Near-Crash and Incident Events (Conflict with a Following Vehicle, Decelerating Lead).

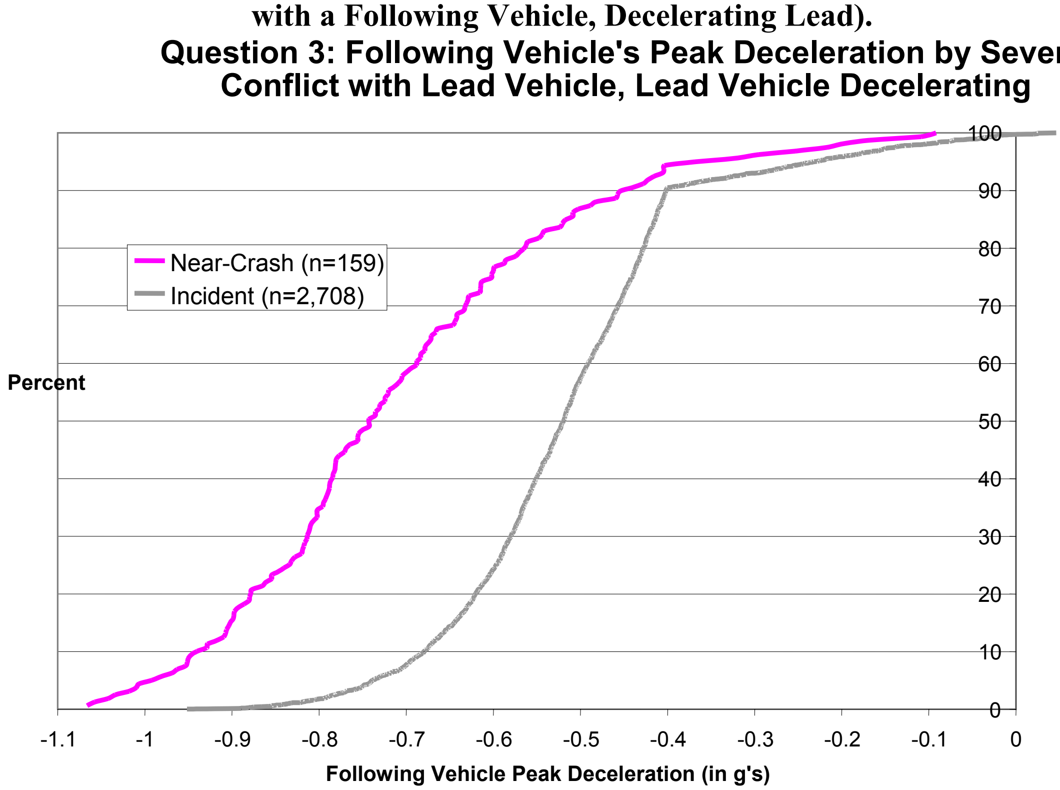

Figure 15. Following-Vehicle Peak Deceleration by Severity Level (Conflict With a Lead Vehicle, Lead-Vehicle Decelerating).

Summary

- The patterns of vehicle headways and TTC values at the onset of lead-vehicle braking across near-crash and incident events are very similar and suggest that the vast majority of drivers were not necessarily following too closely at the onset of lead-vehicle braking.
- Although some drivers adopted short following distances (the 25th percentile values fell under 1 s for both near-crashes and incidents), TTC values were well above imminent crash levels (e.g., 2 s), suggesting that the following drivers were maintaining an acceptable distance from the lead vehicle given their speed at the onset of lead-vehicle braking.
- Data are consistent with the hypothesis that late detection of lead-vehicle braking may lead to heavier braking by the following driver. Peak deceleration levels for following drivers suggest that drivers involved in near-crashes had delays detecting lead-vehicle braking onset relative to drivers involved in incidents. Drivers in near-crashes had higher median peak deceleration levels (0.74*g*) than drivers in incidents (0.51*g*); mean brake response times were 1.3 and 1.0 s for near-crashes and incidents, respectively (refer to Question #1).
- Drivers appear to be more responsive and aware of the severity of events unfolding in the forward view as opposed to those unfolding behind them.

QUESTION 4: LANE CHANGES

To what extent were "following" drivers involved in crashes, near-crashes, and incidents making lane changes and failing to notice a slower car ahead?

The first analysis for this question provides a listing of descriptive statistics for the number of rear-end events that are due to lane changes and merge situations. The second analysis is an examination of the distractions and eyeglance patterns noted for drivers involved in lane-change events to determine where they were looking or what they were distracted by at the onset of the conflict. In every case where it was possible, event onset coincided with the onset of the LV brake lamps. Most cases fell into this category. For curves, event onset coincided with the first instant that the FV driver should have been able to see the LV brake lamps. Where brake light onset could not be seen for some reason, it was inferred from LV deceleration (from radar data).

The data included in this analysis are events for which the following vehicle (FV; always a 100-Car vehicle for this question) performed a lane-change or merge maneuver and in so doing, had a crash, near-crash, or incident with a lead vehicle (LV). The LV in question could be in the FV's originating lane (e.g., the FV changed lanes to avoid a stopped LV) or in the destination lane (e.g., the FV changed lanes and then encountered a stopped LV in the new lane).

The descriptive statistics for conflict with LV lane-change events indicate that this was an uncommon event. There were 6,177 events classified as conflict with a lead vehicle (15 crashes, 380 near-crashes, and 5,782 incidents). Of these, there were 349 (4.8%) with *changing lanes* indicated as the FV pre-incident maneuver (0 crashes, 37 near-crashes, and 312 incidents). There were also 21 (0.3%) events with the FV pre-incident maneuver described as *merging* (2 crashes, 3 near-crashes, and 16 critical incidents). The frequency of various LV pre-incident maneuvers for the FV lane change and merge events is shown in Tables 13 and 14, respectively. The three most common LV maneuvers were stopped in traffic lane, decelerating in traffic lane, and changing lanes. Together, these categories accounted for 91 percent of the lane-change events and 86 percent of the merge events.

Table 13. Lead-vehicle pre-incident maneuvers for following vehicle lane-change events.

LV Pre-incident Maneuver	Event Severity		
	Near-Crash	Incident	Total
Stopped in traffic lane	6 16%	152 49%	158 45%
Decelerating in traffic lane	13 35%	91 29%	104 30%
Changing lanes	16 43%	41 13%	57 16%
Going straight, constant speed	1 3%	16 5%	17 5%
Turning right	0 0%	4 1%	4 1%
Going straight, accelerating	0 0%	4 1%	4 1%
Turning left	0 0%	2 1%	2 1%
Merging	1 3%	1 0%	2 1%
Starting in traffic lane	0 0%	1 0%	1 0%
Total	37 100%	312 100%	349 100%

Table 14. Lead vehicle pre-incident maneuvers for following vehicle-merge events.

LV Pre-incident Maneuver	Event Severity			
	Crash	Near-Crash	Incident	Total
Stopped in traffic lane	1 50%	0 0%	5 31%	6 29%
Decelerating in traffic lane	0 0%	1 33%	6 38%	7 33%
Changing lanes	0 0%	1 33%	4 25%	5 24%
Merging	0 0%	1 33%	1 6%	2 10%
Other	1 50%	0 0%	0 0%	1 5%
Total	2 100%	3 100%	16 100%	21 100%

The next issue to be addressed is whether any of these fairly rare events were caused by visual distraction due to the lane-change maneuver. That is, were the drivers in these events so busy scanning the surrounding traffic preparing to make a lane change that they did not notice the conflicting LV in a timely fashion? The first analysis examines the coded distraction for each event. A second analysis examines the eyeglance patterns recorded for the events. The data reductionists coded each event as distracted or not distracted. For distracted events, the nature of the distraction was noted (e.g., talking/listening to cell phone or eating with utensils). For the purposes of this analysis, the resulting data were then classified into one of four large distraction categories: no distraction, lane-change-related distraction (e.g., left window, left mirror), non-lane-change visual distraction (e.g., dialing cell phone), and non-lane-change cognitive distraction (e.g., talking/listening to cell phone). Table 15 presents the results of this analysis, with lane-change and merge distraction combined since distractions were rare. Note that 78 percent were coded as no distraction, and only 6 percent were coded with a lane-change-related distraction. Of the 81 events coded with distraction, only 23 (28%) were coded as distraction related to the lane-change maneuver itself. When this is put into the larger context of all conflict with lead vehicle events, there were only 23 of 6,177 cases (0.4%) in which a following vehicle driver was merging or changing lanes, and due to the visual demand of the lane-change task, failed to notice a vehicle ahead (which in most cases was stopped or decelerating). However, 100 percent (2 of 2) of the lane change/merge crashes fell into this category, and 50 percent (7 of 14) of the distraction-related near-crash events were also due to lane-change-related distraction.

Table 15. Following-vehicle driver distraction categories for lane-change and merge events.

FV Driver Distraction	Event Severity			
	Crash	Near-Crash	Incident	Total
No Distraction	0 0%	26 65%	262 80%	288 78%
Lane-Change Related Distraction	2 100%	7 18%	14 4%	23 6%
Non-Lane-Change-Related Visual Distraction	0 0%	4 10%	28 9%	32 9%
Non-Lane-Change-Related Cognitive Distraction	0 0%	2 5%	24 7%	26 7%
No Data	0 0%	1 2%	0 0%	1 <1%
Total	2 100%	40 100%	328 100%	370 100%

The data described above include distractions that may have occurred at any time over the course of the event. For the purposes of designing an enhanced rear-signaling system, it is also important to know what the driver was looking at the point in time when the lead vehicle's brake lamps came on. The final analysis for this question went beyond the reductionists' perception of overall event distraction to examine the eyeglance patterns of the drivers at the event onset. As shown in Table 16, in almost two-thirds of the lane-change and merge cases, the drivers were looking forward (visual angle of 0/0) at event onset. In a little over one-third of cases, the FV driver's visual angle could not be determined at event onset due to glare, glasses/sunglasses, darkness, or other conditions. In most cases, these were momentary conditions, and the overall eye-glance patterns could still be determined, including percent EOR time, as discussed in the following section.

Table 16. Following-vehicle driver visual angles at event onset for lane-change and merge events.

FV Driver Visual Angle at Brake Light Onset	Event Severity			
	Crash	Near-Crash	Incident	Total
0/0 (Forward)	1 50%	26 65%	203 61.9%	230 62.2%
30D/15R (HVAC)	0 0%	1 2.5%	0 0%	1 0.3%
30D/30R (Radio)	0 0%	0 0%	1 0.3%	1 0.3%
Not Available	1 50%	13 32.5%	124 37.8%	138 37.3%
Total	2 100%	40 100%	328 100%	370 100%

Eyeglance data were also examined to determine the percent of EOR time during the course of the event. This analysis was intended to explore the idea that even if drivers were looking forward at event onset, there may have been differences in how much overall time was being devoted to the forward view during the event. For the two crashes, drivers spent 20.1 percent of the event time with their eyes off the forward view. The 40 near-crashes had 12.8 percent EOR time. For the 328 incidents, drivers' eyes were off the road 13.3 percent of the time. Given the small size of the dataset, not much can be inferred from these data.

Results from the Question 4 analyses indicate that lane changes and merges rarely lead to a conflict with a lead vehicle. When such conflicts do occur, the LV is usually stopped, decelerating. There does not appear to be a large amount of distraction associated with lane-change and merge events. For those events that do involve distraction at some point during the event, about one-fourth involve task-related distraction (related to the lane change or merge). Eyeglance analysis indicates that the driver's eyes were usually forward when the lead-vehicle brake lamps came on, and that the EOR time during the course of the event was not unusual (13.3 percent over all severities). The overall results do not present any indication that lane-change and merge conflicts with a LV would require different countermeasures than those that might be effective for other categories of conflict with lead vehicle.

QUESTION 5: SPEED AND HEADWAY

What were the vehicle speeds and headways prior to the point of closest headway?

This question sought to characterize vehicle kinematics situations for crashes, near-crashes and critical incidents captured as part of the 100-Car Study. Specifically, it quantified vehicle speed and following distance (e.g., headway) values for rear-end crashes, near-crashes, and incidents. Table 17 presents the total number of rear-end conflict events by type and severity level. Conflicts with a lead vehicle (where the subject vehicle, or instrumented, vehicle hit the lead vehicle) were more common for near-crashes and incidents than crashes. Crashes were more evenly distributed across the two types of events with 56 percent involving conflicts with a lead vehicle and 44 percent with a following vehicle.

Table 17. Number of events by severity level and type/nature.

	Severity Level of Rear-End Event			
Nature of Event	**Crash**	**Near-crash**	**Incident**	**Total**
Conflict with a following vehicle (subject-vehicle struck from behind)	12 44%	70 16%	764 12%	846 12%
Conflict with a lead vehicle (subject-vehicle striking lead vehicle)	15 56%	380 84%	5,783 88%	6,178 88%
Total	27 <1%	450 6%	6,547 93%	7,024 100%

The data that follow quantify vehicle speed, headway, and TTC measures prior to the closest headway for each conflict event. Measures were calculated by first identifying the point of closest headway and then averaging over two different time-based intervals prior to that point corresponding to 1 and 3 s before the conflict. Together, these intervals provide a picture of the pre-incident profiles at a point before the conflict (2 s out), and again immediately before the incident (1 s out).

Mean, min/max ranges, and standard deviation data for speed, headway and TTC are presented in Table 18 for crashes, near-crashes, and incidents. Table 19 also provides percentile values for mean speed, headway, and TTC. Figures 16 to 21 plot the cumulative frequency distributions showing the percentiles for mean speed, minimum headway, and minimum TTC values across the three severity levels and two time samples.

Table 18. Measures of central tendency (mean, minimum, maximum, and standard deviation values) for vehicle speed, headway, and TTC across crashes, near-crashes, and incidents. Values represent samples averaged over intervals of 3 s and 1 s prior to closest headway.

	Time Prior to Closest Headway:						
	3 Second				1 Second		
Measure	Crash	Near-Crash	Incident		Crash	Near-Crash	Incident
Mean Speed	15.18	29.07	28.34		16.95	26.26	26.59
Max Speed	17.74	33.15	32.07		17.56	28.79	28.65
Min Speed	12.81	24.00	24.20		16.23	24.29	25.05
SD Speed	1.74	3.06	2.62		0.50	1.72	1.38
Mean Headway	1.92	1.65	1.87		0.99	1.15	1.40
Max Headway	4.01	3.78	4.09		1.63	2.13	2.50
Min Headway	0.42	0.45	0.62		0.57	0.45	0.62
SD Headway	1.35	0.98	1.02		0.41	0.62	0.69
Mean Time-to-Collision	2.56	3.05	3.59		1.92	1.81	2.71
Max Time-to-Collision	5.02	6.34	6.41		2.86	2.93	3.86
Min Time-to-Collision	1.19	1.23	1.97		1.28	1.13	1.98
SD Time-to-Collision	1.14	1.60	1.39		0.59	0.65	0.70

Table 19. Percentile values for mean speed, headway, and TTC values for crashes, near-crashes, and incidents at 3 s and 1 s prior to closest headway.

	Percentile Values, Time Prior to Closest Headway:										
	3 Second						1 Second				
	10th	25th	50th	75th	90th		10th	25th	50th	75th	90th
Crash											
Mean Speed (mph)	2.20	4.88	8.89	27.79	35.43		1.86	3.78	5.93	31.23	42.53
Mean Headway (sec)	0.30	0.55	1.46	2.38	3.52		0.02	0.28	0.65	0.96	2.68
Mean TTC (sec)	0.63	1.18	1.65	3.91	6.32		0.59	0.69	1.05	3.62	4.26
Near Crash											
Mean Speed (mph)	11.38	17.94	26.25	38.99	50.67		7.85	14.34	23.10	36.43	49.03
Mean Headway (sec)	0.58	0.82	1.22	2.05	3.19		0.33	0.48	0.77	1.33	2.46
Mean TTC (sec)	1.06	1.43	2.11	3.61	5.73		0.66	0.83	1.20	2.08	4.73
Incident											
Mean Speed (mph)	11.84	17.90	25.28	36.86	49.41		10.16	15.25	23.10	35.92	49.20
Mean Headway (sec)	0.65	0.95	1.49	2.33	3.60		0.44	0.64	0.99	1.67	2.89
Mean TTC (sec)	1.27	1.73	2.56	4.18	6.22		0.86	1.17	1.76	3.10	5.38

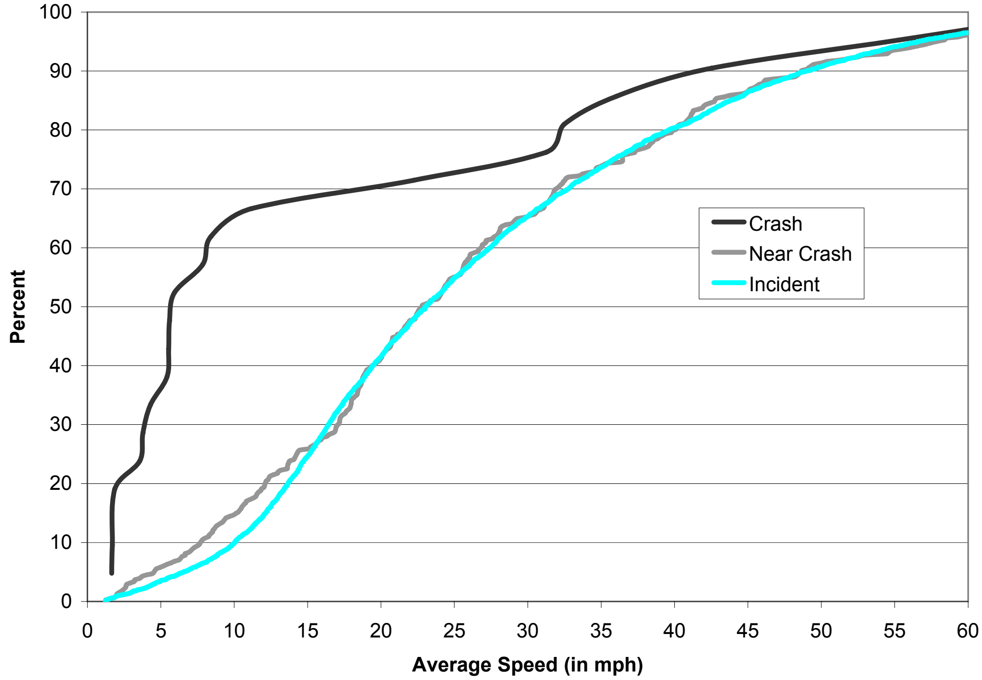

Figure 16. Distribution of Average Speed by Severity Level (1 s before closest headway).

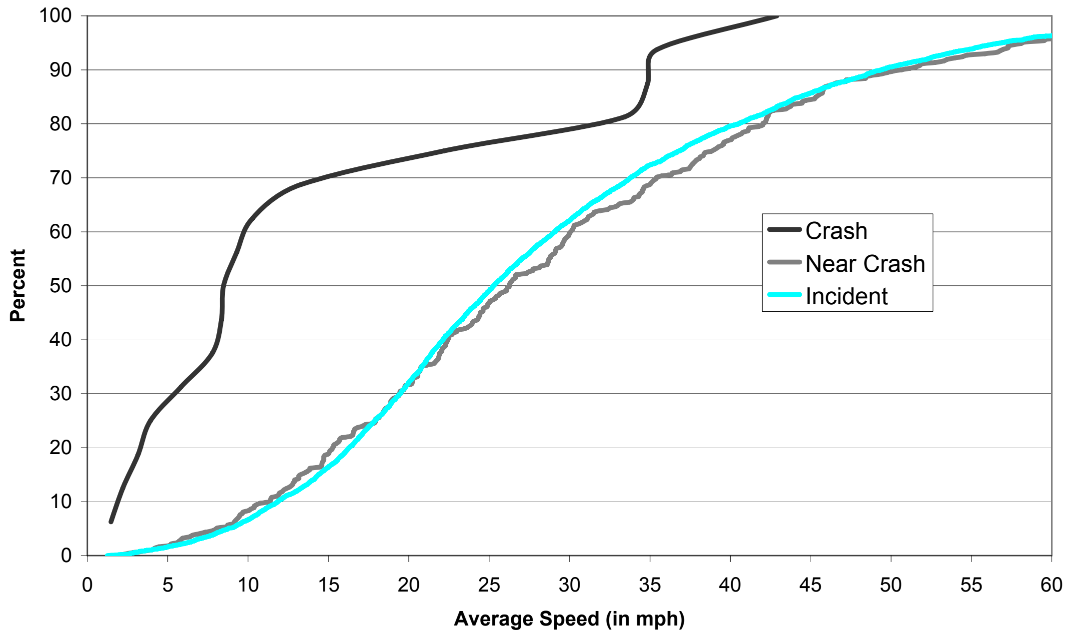

Figure 17. Distribution of Average Speed by Severity Level (3 s before closest headway).

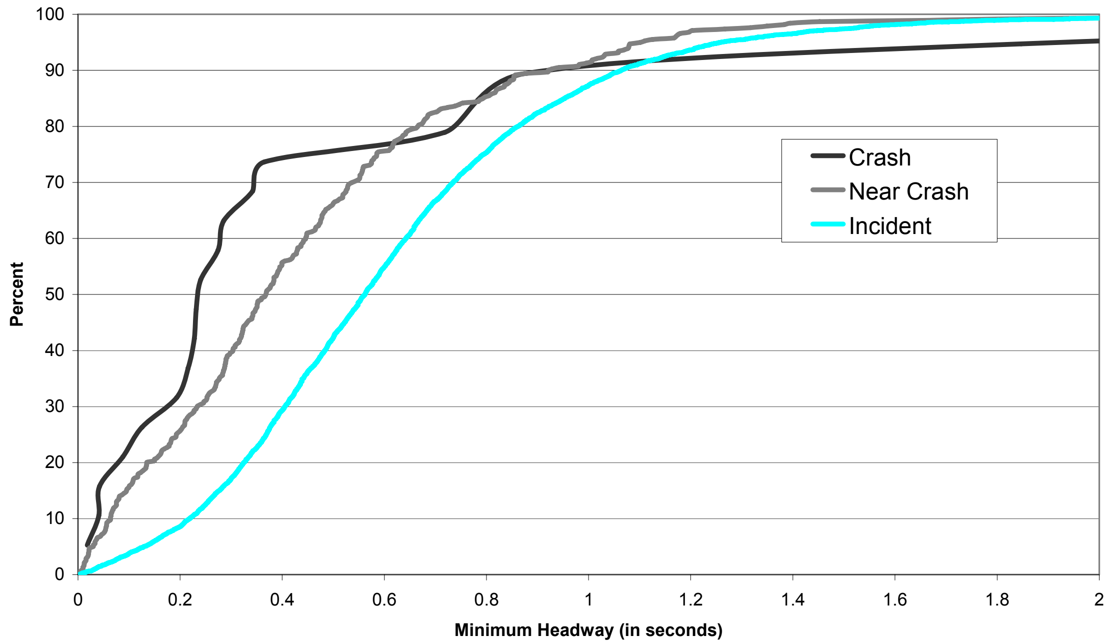

Figure 18. Distribution of Minimum Headways by Severity Level (1 s before closest headway).

Question 5: Distribution of Minimum Headways by Severity Level

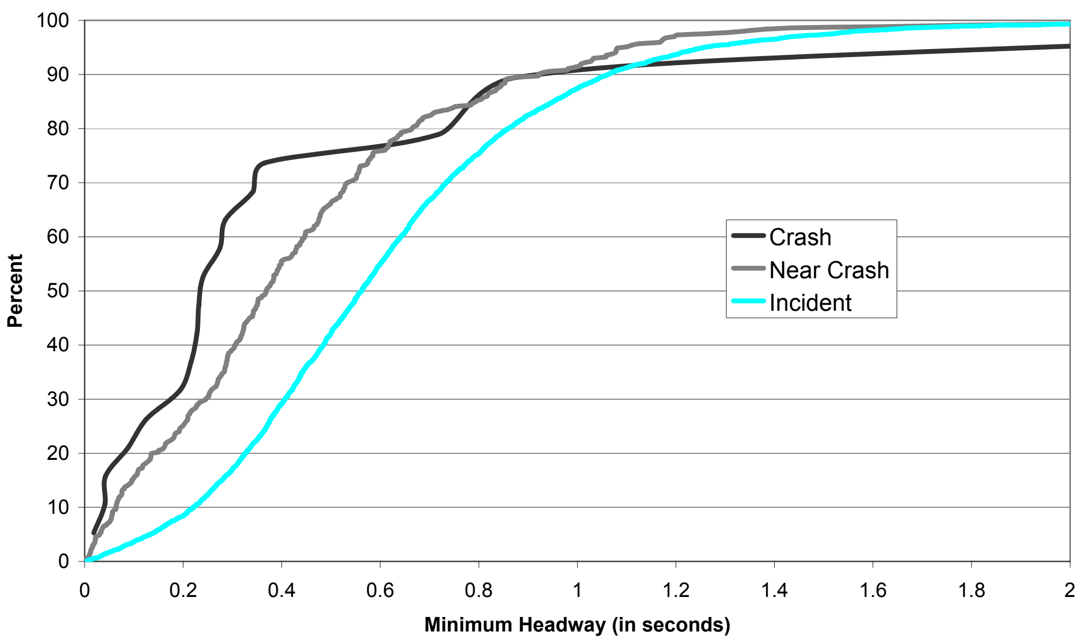

Figure 19. Distribution of Minimum Headways by Severity Level (3 s before closest headway).

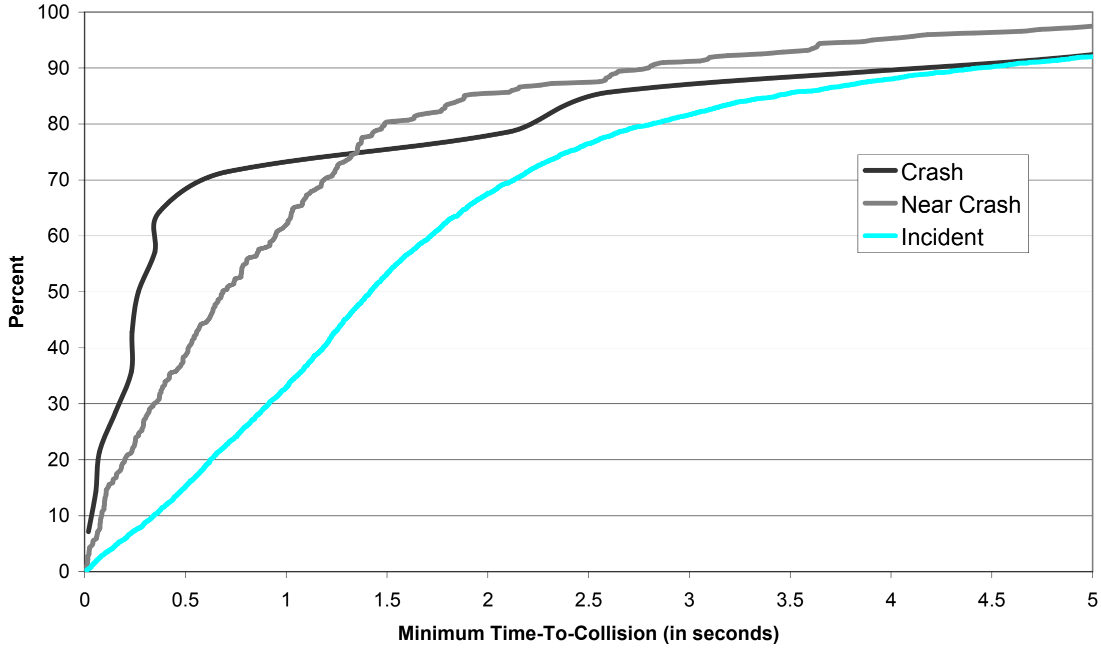

Figure 20. Distribution of Minimum TTC by Severity Level (1 s before closest headway).

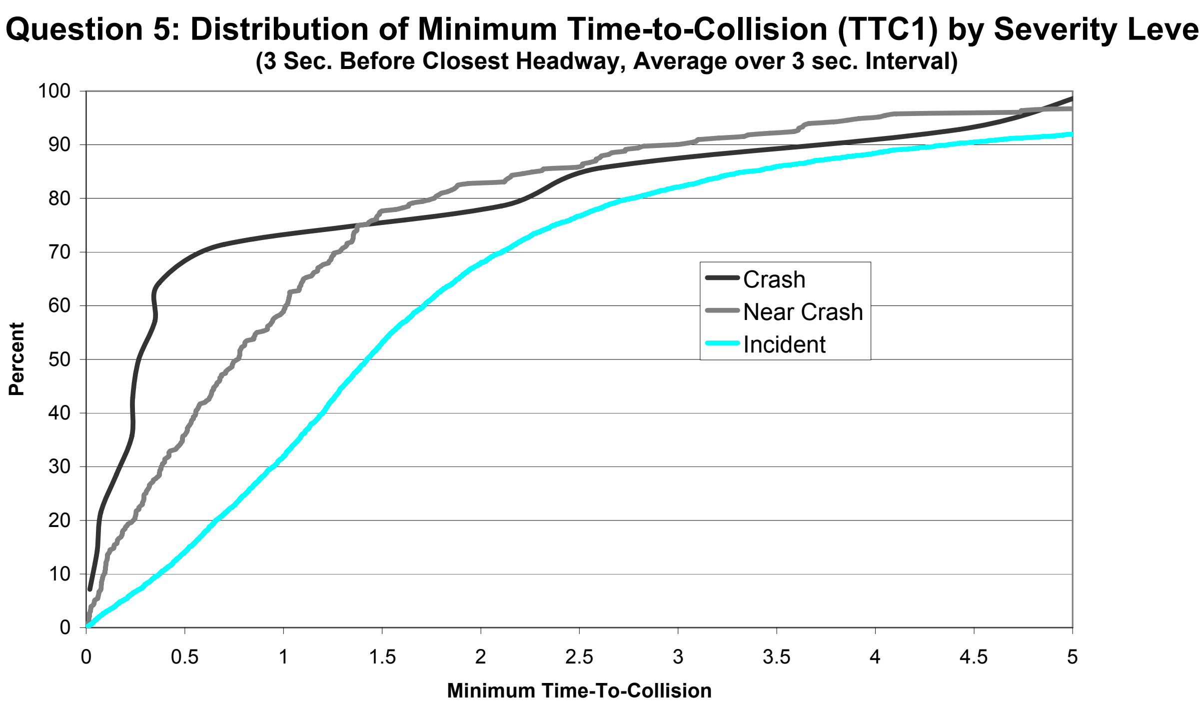

Figure 21. Distribution of Minimum TTC by Severity Level (3 s before closest headway).

SUMMARY

The following observations are noteworthy:

- Crashes and near-crashes appear to have similar profiles in many cases. For example, distributions for mean TTC values for crashes closely resemble those for near-crashes (refer to the Figure 22 below based on values in Table 19). This suggests that driver actions taken immediately before the event strongly influenced the outcome of rear-end conflicts.
- Crashes tended to occur at lower speeds than near-crashes or incidents. Crash speeds averaged 15.2 mph compared to higher mean speeds associated with near-crashes (29.1 mph) and incidents (28.3 mph) at 3 s prior to the event (see Table 18). Mean speed percentile distributions shown in the Figure 23 below illustrate this point (from Table 19). Further examination revealed that the lower crash speeds observed for crashes are attributable, in part, to the environment and the pre-incident maneuver taken by the driver. The vast majority of near-crashes (69%) and incidents (62%) occurred at non-junctions, while only 36 percent of crashes occurred in non–junction areas; the vast majority of crashes took place at or near intersections or ramps which tend to be lower speed environments. Drivers involved in near-crashes and incidents also tended to be going straight at a constant speed (45% and 44%, respectively), while only 12 percent of crash-involved drivers were driving straight at a constant speed (most were decelerating in traffic).

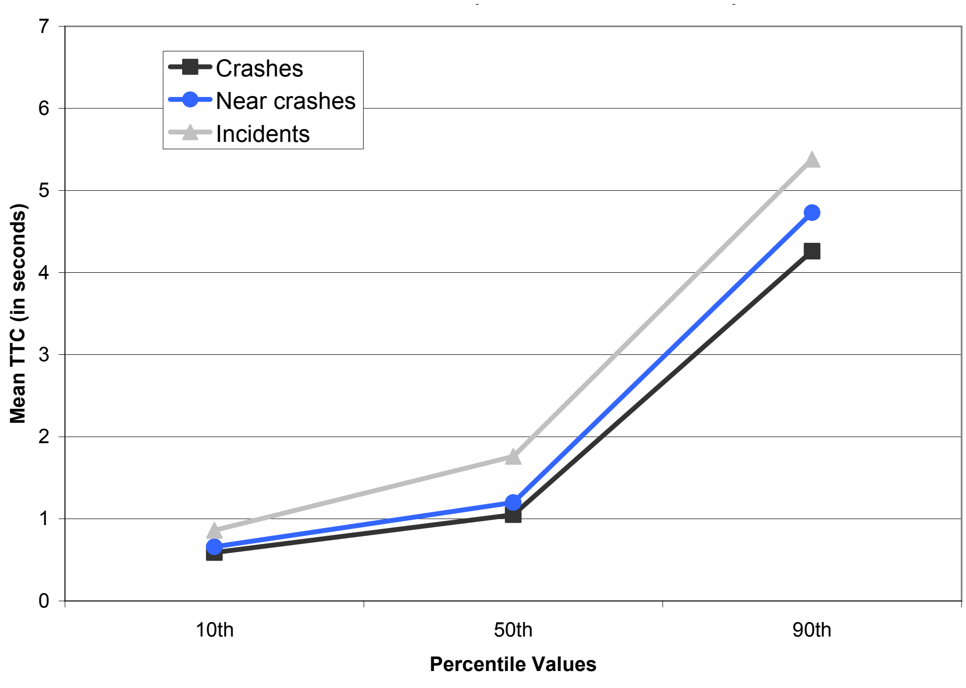

Figure 22. Mean TTC Percentile Values across Severity Levels (1 s before closest headway).

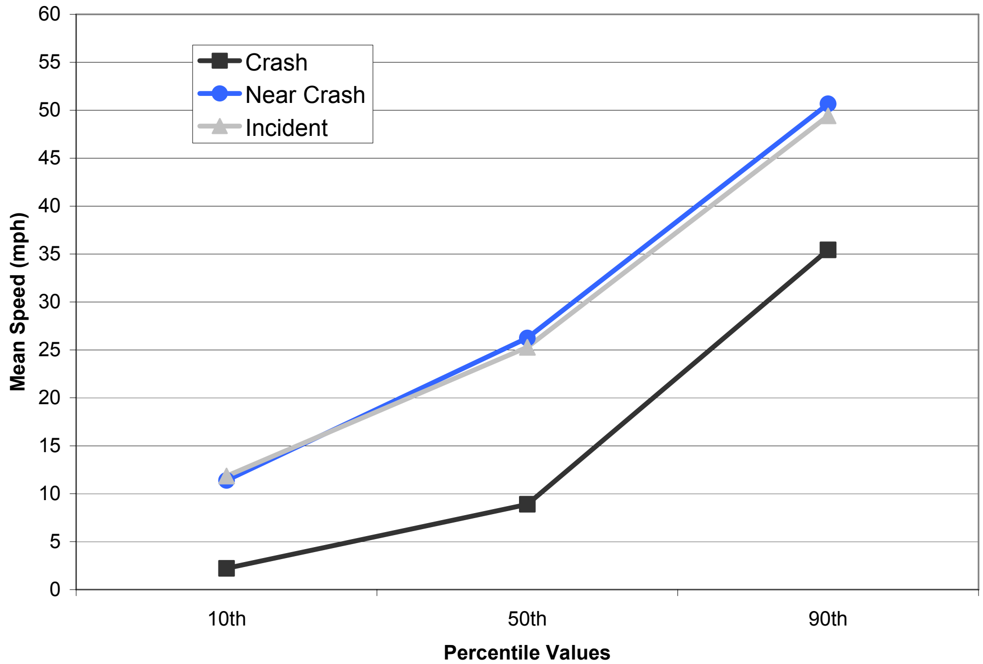

Figure 23. Percentile Values of Mean Speeds across Severity Levels (3 s before closest headway).

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QUESTION 6: LEAD-VEHICLE STOPPED/DECELERATION STATUS

What proportion of rear-end events involve lead-vehicle stopped, mild braking, hard braking, or just going slow without braking?

Of the 7,024 observed rear-end events, 45 percent involved a decelerating lead vehicle, 38 percent involved a stopped lead vehicle, 2 percent involved a slower moving lead vehicle, and 15 percent occurred under various other situations. Table 20 presents these rear-end events (crashes, near-crashes, and incidents) as a function of the status of the lead vehicle. Crashes were predominately characterized by situations in which the lead vehicle was stopped, whereas near-crashes and incidents were more evenly distributed across instances of both stopped and decelerating lead vehicles. Events triggered by a decelerating lead vehicle tended to involve moderate to heavy braking by the lead vehicle. In near-crash situations where the lead vehicle is decelerating, for example, approximately 56 percent of the lead-vehicle peak decelerations (109 out of 194) were above 0.55*g*, and 22 percent involved moderate braking (peak deceleration between 0.25 and 0.55*g*).

Table 20. Disposition of Lead Vehicle Across Rear-End Events (Crashes, Near-Crashes, and Incidents).

	Severity Level of Rear-End Event							
	Crash		Near-Crash		Incident		Total	
	N	%	N	%	N	%	N	%
Lead Vehicle Stopped	**22**	**81%**	**145**	**32%**	**2514**	**38%**	**2,681**	**38%**
< 2 seconds	10	37%	101	22%	1,135	17%	1246	18%
> 2 seconds	12	44%	44	10%	1,379	21%	1,435	20%
Lead Vehicle Decelerating	**4**	**15%**	**194**	**43%**	**2947**	**45%**	**3145**	**45%**
Light (<.25*g*)	0	0%	20	4%	301	5%	321	5%
Moderate (.25-.55*g*)	0	0%	43	10%	1,460	22%	1,503	21%
Heavy (>.55*g*)	2	7%	109	24%	975	15%	1,086	15%
Missing	2	7%	22	5%	211	3%	235	3%
LV Moving Slower, Constant Speed	**0**	**0%**	**6**	**1%**	**149**	**2%**	**155**	**2%**
Other	**1**	**4%**	**105**	**23%**	**937**	**14%**	**1,043**	**15%**
Total	**27**	**0.4%**	**450**	**6%**	**6,547**	**93%**	**7,024**	**100%**

Table 21 presents the near-crash data according to the speed of the following vehicle. The majority of cases (approximately 56%) occurred while the lead vehicle was traveling under 40 mph; most of these involved following vehicle speeds of between 21 and 40 mph. Figure 24 also suggests that with the exception of moderate lead-vehicle deceleration, TTC values were very similar across stopped and lead-vehicle braking profiles.

Table 21. Near-Crashes, Distribution of Following Vehicle Speed by Lead-Vehicle Disposition.

	Lead Vehicle Stopped				LV Moving slower, constant speed		Lead Vehicle Decelerating						Missing/ Other	Total	
	<2sec		>2sec				Light (<.25g)		Moderate (.25-.55g)		Hard (>.55g)				
	n	%	n	%	n	%	n	%	n	%	n	%	n	n	%
Breakdown by Following Vehicle Speed (in mph)															
0-10	20	4%	4	1%	1	0%	0	0%	0	0%	1	0%		26	6%
11-20	17	4%	9	2%	1	0%	3	1%	6	1%	7	2%		43	10%
21-30	33	7%	9	2%	1	0%	5	2%	13	3%	28	6%		89	20%
31-40	18	4%	17	4%	0	0%	7	2%	14	3%	34	8%		90	20%
41-50	7	2%	3	1%	0	0%	5	1%	4	1%	23	5%		42	9%
51-60	1	0%	1	0%	3	1%	0	0%	4	1%	9	2%		18	4%
60+	0	0%	0	0%	1	0%	0	0%	2	0%	7	2%		10	2%
Subtotal	96	21%	43	10%	7	2%	20	4%	43	10%	109	24%	105	423	94%
Missing	5	1%	1	0%	0	0%	0	0%	0	0%	0	0%	22	28	6%
Overall	101	22%	44	10%	7	2%	20	4%	43	10%	109	24%	127	451	100%

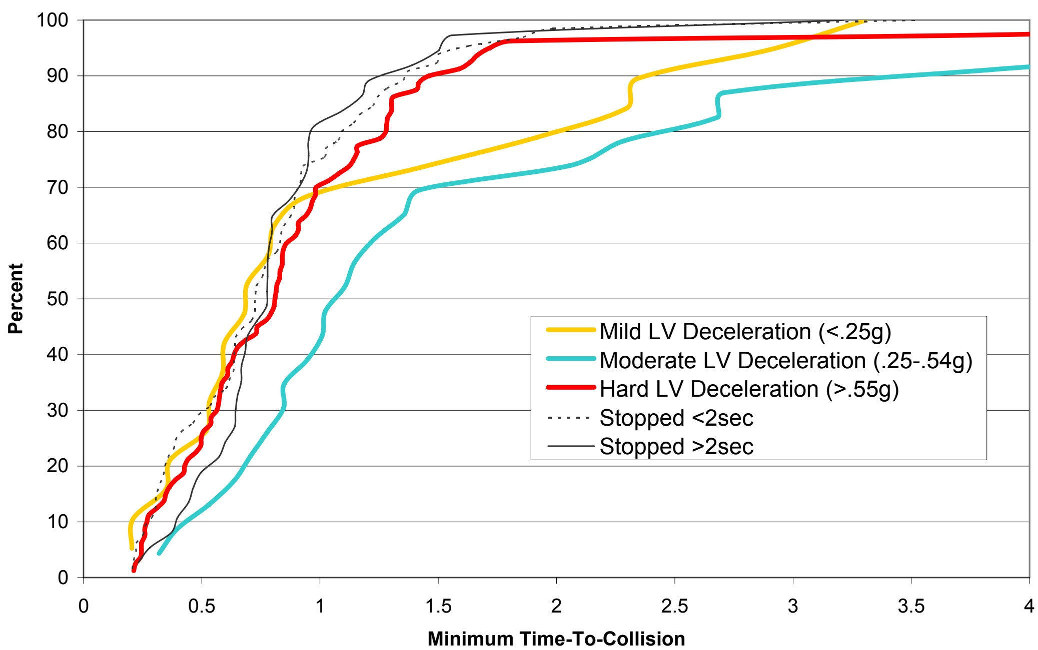

Figure 24. Distributions of Minimum TTC across Lead-Vehicle-Stopped/Deceleration Status (Near-Crashes, Conflicts with a Decelerating Lead Vehicle).

SUMMARY

- Available crash data suggest that enhanced rear-signaling systems which are designed to alert drivers to the presence of a stopped lead vehicle have the potential, if effective, to reduce the incidence of rear-end crashes. The majority of observed rear-end crashes in the sample (81%) were collisions with a stopped lead vehicle. Such a system would also benefit safety by reducing the incidence of near-crashes and incidents.
- A rear-signaling system that extinguishes somewhat after a vehicle comes to a complete stop should provide benefit by reducing a substantial percentage of collisions with stopped lead vehicles, while reducing annoyance caused by extended signaling after a vehicle is stopped. Data suggest this type of signal would address approximately 45 percent (10 out of 22) of stopped-lead-vehicle crashes.
- A rear-signaling system that communicates moderate to hard lead-vehicle decelerations can potentially decrease the incidence of rear-end near-crashes and incidents. For example, a system to signal hard lead-vehicle decelerations (peak braking above 0.55*g*) could potentially address 56 percent (109 out of 194) of near-crash events.

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QUESTION 7: AVOIDANCE MANEUVERS

What avoidance maneuvers did the driver take (e.g., just braking, steering, nothing, both)?

The answer to this question is approached in several ways in this section. The first method is to simply examine the avoidance maneuvers taken, regardless of other factors. The second method is to examine the avoidance maneuvers taken in the presence of various lead-vehicle deceleration and stopping behaviors. The third method is to examine the avoidance maneuvers in relation to various TTC values between the lead and following vehicles. The analyses include only conflicts with a lead vehicle with the 100-Car vehicle as the FV. Most of the events fell into this category. There were 15 crashes, 380 near-crashes, and 5,783 incidents in the resulting database of conflicts with lead vehicle.

Table 22 provides the distribution of events (by severity) for each avoidance maneuver. As can be seen, the most common driver response to a conflict with a lead vehicle was braking alone. This response accounted for 84 percent of all events, including 40 percent of crashes, 70 percent of near-crashes, and 85 percent of incidents. The next most common response was to brake and steer (either right or left), which accounted for 10 percent of all events. Steering alone (either right or left) accounted for 4 percent of all events. The remaining responses thus accounted for about 2 percent of all events. Where steering occurred, it was always very close to being equally probable in the left or right directions.

Table 22. Frequency and percent of occurrence of a particular driver response for crashes, near-crashes, and incidents.

	Severity			
Driver Response	**Crash**	**Near-crash**	**Incident**	**Total**
Braked	6 40.0%	265 69.7%	4,931 85.3%	5,202 84.2%
Braked and steered (either direction)	1 6.7%	104 27.4%	538 9.3%	643 10.4%
Steered (either direction)	0 0.0%	7 1.8%	207 3.6%	214 3.5%
Accelerated and steered (either direction)	0 0.0%	4 1.1%	69 1.2%	73 1.2%
No reaction	7 46.7%	0 0.0%	29 0.5%	36 0.6%
Other actions	1 6.7%	0 0.0%	9 0.2%	10 0.2%
Total	15 100.0%	380 100.0%	5,783 100.0%	6,178 100.0%

The next analysis examined FV responses based on LV kinematics (stopped, decelerating at various levels). Because the braking response dominated the data to such a great degree, the remaining analyses based on LV kinematics and TTC do not provide as much insight as they might if the driver responses were more equally distributed. Deceleration values were not available for all cases (e.g., when the LV was accelerating), so the total number of incidents considered in Table 23 is somewhat lower than for the first analysis (5,359 vs. 6,178). Of these, 14 were crashes, 277 were near-crashes, and 5,068 were incidents. As shown in Figure 25, when the cases are considered on a percentage basis, FV drivers braked about 90 percent of the time when the lead-vehicle maneuver could be considered to be moderate to severe (either stopped or braking >0.25*g*). When the LV exhibited a milder maneuver (moving at slower, constant speed or decelerating at ≤0.25*g*), the FV drivers were much more likely to exhibit a range of responses. The braking, braking + steering, steering, and accelerating + steering responses were all fairly well represented for these two LV maneuvers. Based on these results, braking seems to be the preferred or instinctual FV response to a moderate or severe LV maneuver, while a wide range of FV responses are used with milder LV maneuvers.

Table 23. Frequency and percent of occurrence of a particular driver response based on lead-vehicle kinematics (deceleration values represent peak decelerations).

Driver Response	**LV stopped > 2 s**	**LV stopped ≤ 2 s**	**LV slower, constant speed**	**LV light decel. (≤ 0.25*g*)**	**LV mod. decel. (0.25*g* - 0.55*g*)**	**LV heavy decel. (>0.55*g*)**
Braked	1,192 88%	1,093 93%	62 38%	93 40%	1,240 89%	927 90%
Braked and steered (either direction)	109 8%	60 5%	45 27%	72 31%	139 10%	100 10%
Steered (either direction)	38 3%	10 1%	39 24%	48 21%	20 1%	5 0%
Accelerated and steered (either direction)	11 1%	5 0%	16 10%	19 8%	2 0%	3 0%
No reaction	3 0%	3 0%	1 1%	0 0%	0 0%	0 0%
Other actions	3 0%	0 0%	1 1%	0 0%	0 0%	0 0%
Total	1,356 100%	1,171 100%	164 100%	232 100%	1,401 100%	1,035 100%

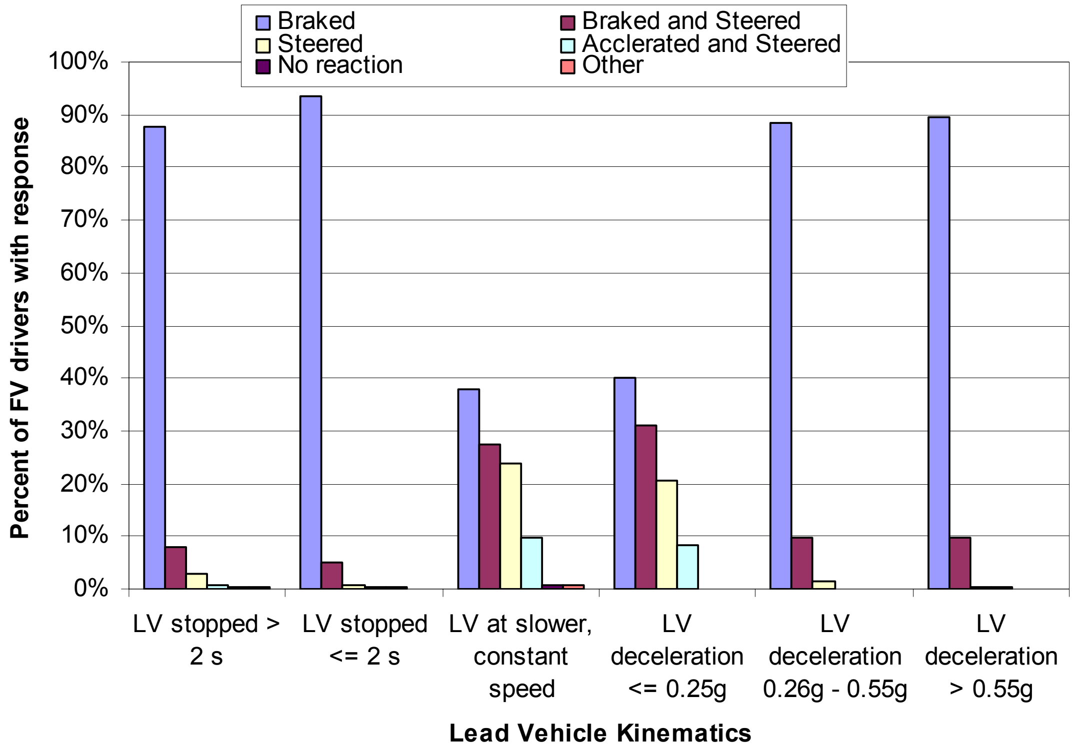

Figure 25. Percent of occurrence of FV-driver responses based on lead-vehicle kinematics scenarios.

The final analysis examined FV-driver response given various levels of minimum TTC to the LV. Values for TTC were not available for all conflict-with-LV cases, and the resulting dataset contained 13 crashes, 272 near-crashes, and 5047 incidents, for a total of 5,332 events. As shown in Table 24 and Figure 26, very short (<0.5 s) and very long (≥ 1.5 s) TTCs resulted in more varied responses by the FV driver. Two-thirds of the events had a minimum TTC between these extremes (0.5 s to 1.49 s); FV drivers braked about 90 percent of the time in response to these moderate TTCs. It is interesting to note that at the very short TTC values, drivers chose to both brake and steer 14 percent of the time, indicating driver perception that the situation was severe enough that braking alone would not be an adequate response.

Table 24. Frequency and percent of occurrence of a particular driver response based on minimum TTC to LV during the event.

Driver Response	TTC ≤0.5s	TTC >0.5s to 1.0s	TTC >1.0s to 1.5s	TTC >1.5s to 2.0s	TTC >2.0s to 2.5s	TTC >2.5s to 3.0s	TTC >3.0s
Braked	365 81%	1,721 91%	1,450 89%	493 83%	168 76%	60 68%	330 73%
Braked and steered (either direction)	61 14%	124 7%	130 8%	70 12%	34 15%	11 13%	92 20%
Steered (either direction)	17 4%	36 2%	31 2%	21 4%	16 7%	11 13%	25 6%
Accelerated and steered (either direction)	5 1%	16 1%	12 1%	11 2%	3 1%	4 5%	5 1%
No reaction	2 0%	1 0%	1 0%	0 0%	0 0%	2 2%	0 0%
Other actions	0 0%	1 0%	1 0%	1 0%	0 0%	0 0%	1 0%
Total	450 100%	1,899 100%	1,625 100%	596 100%	221 100%	88 100%	453 100%

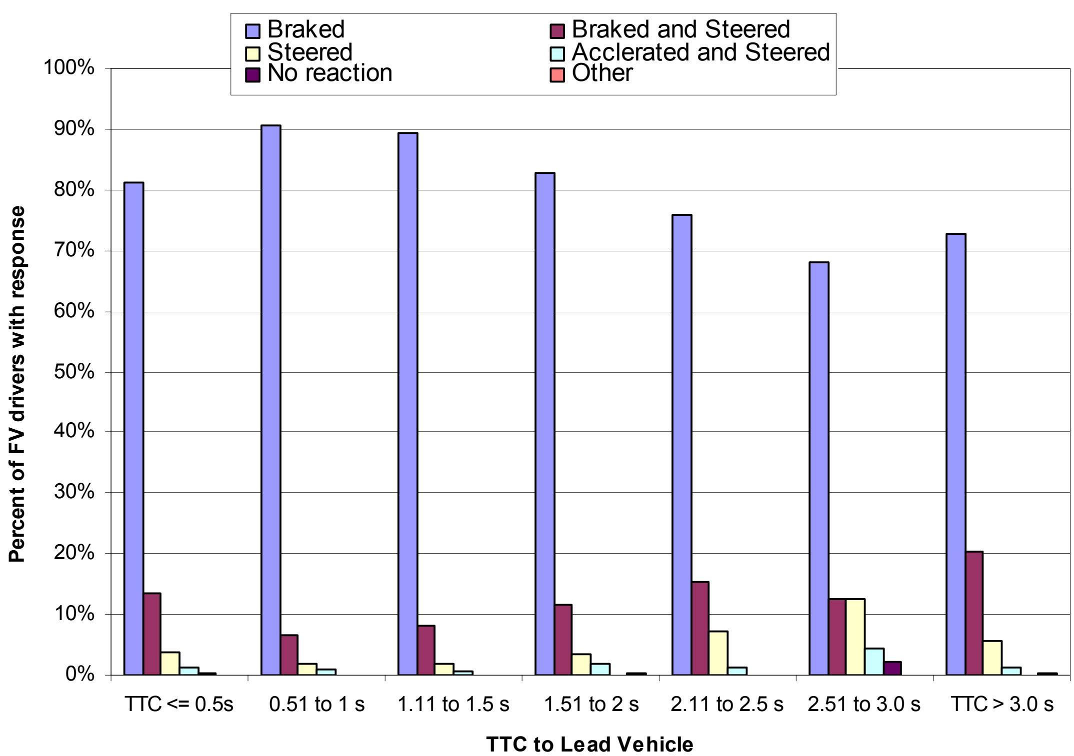

Figure 26. Percent of occurrence of FV-driver responses based on minimum TTC to lead vehicle.

A database developed for Question 3 contained continuous minimum TTC values, as compared to the categorized values used for Table 24 and Figure 26. This database (consisting of 11 crashes, 292 near-crashes, and 4,673 incidents) was used to develop TTC distributions for various FV-driver responses. As shown in Figure 27, the 50th percentile minimum TTC for all responses was less than 2 s, while the 90th percentile minimum TTC for all responses was slightly over 5 s. The braked and the braked + steered responses have almost identical distributions, with the other four responses varying only slightly from these. In general, the distribution of responses only began to vary noticeably once the minimum TTC was a little greater than 1s.

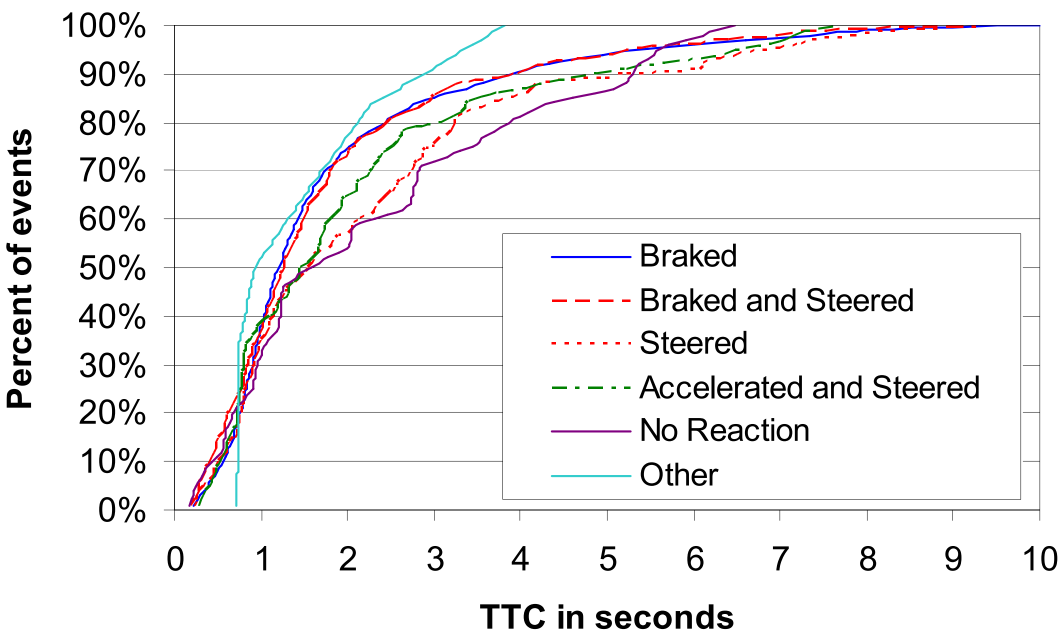

Figure 27. Distribution of FV-driver responses based on minimum TTC to lead vehicle.

These analyses showed that FV-driver response to an event involving a lead vehicle overwhelmingly involved braking, with the FV driver braking in 84 percent of all events and braking and steering in 10 percent of all events. In nearly half of the crashes, there was no driver reaction to the event. When lead-vehicle kinematics scenarios are considered, braking seems to be the preferred or instinctual FV response to a moderate or severe LV maneuver (such as stopped or moderate to hard deceleration), while a wide range of FV responses are used with milder LV maneuvers (such as moving at lower constant speed or mild deceleration). An examination of TTC to the lead vehicle revealed that short and long TTCs resulted in more varied responses by the FV driver, while FV drivers braked about 90 percent of the time in response to moderate TTCs. At the shortest TTC values, drivers chose to both brake and steer 14 percent of the time, indicating that braking alone may not have been enough to prevent a crash. The distributions of FV driver responses with respect to TTC were fairly similar for all responses, especially for TTCs of less than 1.5 s.

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QUESTION 8: INTERSECTION BRAKING PATTERNS

What were the braking levels of drivers who had near-crashes versus those in crashes versus those just braking to a stop sign or traffic signal? Are there factors that can reliably classify situations leading to high braking from those leading to low braking levels?

The 100-Car data analyses conducted to date have not considered the role of intersections except to classify whether or not the crash or near-crash occurred at an intersection/junction. This question required additional data reduction since the databases for questions up to this point do not include baseline data. Several steps were used in answering this question, including:

1. Develop a set of intersection clusters based on the geographical locations of crashes, near-crashes, and incidents.
    a. Validate that these events are potentially related to the presence of an intersection.
    b. Determine peak deceleration values for each event.
2. Develop a software tool to go through the 100-Car data and find events happening near the intersections of interest.
    a. Validate each potential baseline event according to whether it was the same driver, same intersection, same direction, and whether the event resulted in a stop.
    b. Reduce each valid baseline event with certain classification variables as well as peak deceleration (note – the peak deceleration values have not yet been obtained for the baseline group, so this analysis is not yet complete).
3. Analyze the difference, if any, between the baseline and event data.

Because the process for this question was so complex, it took longer than any of the other questions. Considerable research design, programming, and data reduction resources were used in completing each of the steps. Each step will be described briefly, followed by the results.

DEVELOP A SET OF INTERSECTION CLUSTERS

The GPS coordinates of all rear-end crashes, near-crashes, and incidents were mapped using the MapPoint program (Figure 28). A total of 4,325 incidents had valid GPS coordinates and were located in the northern Virginia, District of Columbia, and Maryland areas. This top level map was then zoomed in on and examined area by area to determine whether any of the events seemed to follow a geographical pattern related to intersections (thus belonged to an intersection "cluster"). A cluster was defined as having at least five near-crashes and incidents, or at least one crash and near-crash. Figure 29 presents an example of one such cluster, while Table 25 presents the entire set of 50 clusters (comprising 1 crash, 32 near-crashes, and 329 incidents).

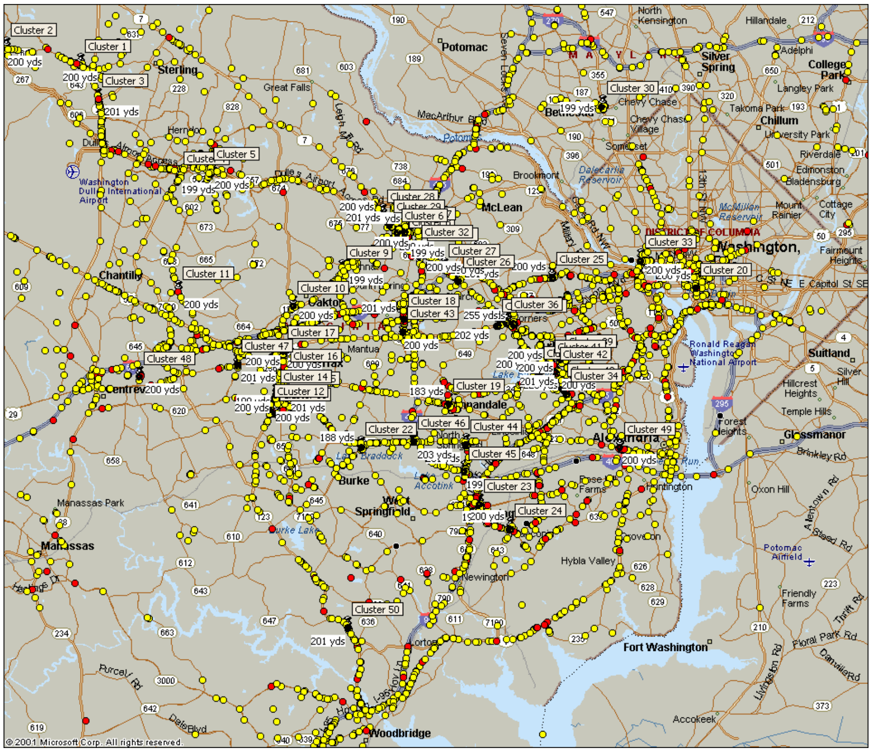

Figure 28. All rear-end crashes (black dots), near-crashes (red dots), and incidents (yellow dots) occurring in the northern Virginia, District of Columbia, and Maryland areas.

Figure 29. Intersection cluster example, showing seven incidents within 600 ft of the intersection of Waxpool Road and Pacific Boulevard. Note that one near-crash and two other incidents were outside this range.

Table 25. All intersection clusters.

Cluster	Primary Street	Cross Street	Crashes	Near-Crashes	Incidents
1	Waxpool Rd.	Pacific Blvd.	0	0	7
2	Waxpool Rd.	Shellhorn Rd.	0	0	6
3	Sully Rd.	S. Sterling Rd.	0	1	5
4	Sunrise Valley Dr.	Fairfax Cty. Pkwy.	0	2	3
5	Reston Pkwy.	Dulles Tollroad Interchange	0	3	11
6	Leesurg Pike	Chain Bridge Rd.	0	0	7
7	International Dr.	Chain Bridge Rd.	0	0	9
8	Leesurg Pike	International Dr.	0	0	7
9	Maple Rd.	Lawyer's Rd. NW	0	0	6
10	Chain Bridge Rd.	Hunter Mill Rd.	0	2	4
11	Rugby Rd.	West Ox. Rd.	1	1	0
12	Braddock Rd.	Ox Rd.	0	0	6
13	Braddock Rd.	Roanoke Ln.	0	1	5
14	University Dr.	Ox Rd.	0	1	10
15	Rappahannock Ln.	Patriot Circle	0	0	16
16	University Dr.	Main St.	0	1	10
17	Chain Bridge Rd.	Hwy. 50/29	0	0	8
18	Gallows Rd.	Hwy. 237/29	0	2	6
19	Little River Trnpk.	Annandale Rd.	0	0	7
20	14th St. NW	Madison Dr. NW	0	1	6
21	Jeff Davis Hwy.	Blackburn Rd.	0	0	6
22	Rolling Rd.	Burke Lake Rd.	0	0	9
23	Franconia Rd.	Commerce St.	0	1	9
24	Franconia-Springfield Pkwy.	Beulah St.	0	1	7
25	N. Cameron St.	Lee Hwy.	0	0	6
26	Leesurg Pike	W. Broad St.	0	1	4
27	Leesurg Pike	Idylwood Rd.	0	0	7
28	Leesurg Pike	Springhill Rd.	0	1	4
29	Leesurg Pike	Gosnell Rd.	0	0	5
30	Wisconsin Ave.	East-West Hwy.	0	0	5
31	Leesurg Pike	Ramada Rd.	0	0	5
32	Leesurg Pike	I-495 on ramp area	0	2	5
33	Key Bridge	M St. NW	0	0	8
34	Seminary Rd.	Fairbanks Ave.	0	1	11
35	Leesurg Pike	Arlington Blvd. (7 Corners #1)	0	2	4
36	Arlington Blvd.	Broad St. (7 Corners #2)	0	1	8
37	Arlington Blvd.	South St. (7 Corners #3)	0	0	5
38	Columbia Pike	Lacy Blvd.	0	0	6
39	Columbia Pike	Carlin Springs Rd.	0	0	6
40	Seminary Rd.	Fillmore Ave.	0	0	7
41	Leesurg Pike	Columbia Pike Interchange	0	1	4
42	Seminary Rd.	Scoville St.	0	1	7

Cluster	Primary Street	Cross Street	Crashes	Near-Crashes	Incidents
43	Gallows Rd.	Gatehouse Rd.	0	1	9
44	Backlick Rd.	Matthew Pl.	0	0	7
45	Backlick Rd.	I-495 onramp area	0	0	10
46	Braddock Rd.	I-495 onramp area	0	0	7
47	Lee Hwy.	Shirley Gate Rd.	0	0	6
48	Stringfellow Rd.	Autumn Willow Dr.	0	1	4
49	Duke St.	Yale St.	0	2	3
50	Ox Rd.	Palmer Dr.	0	1	6
Total = 362 Events			**1**	**32**	**329**

Once this set of events was created, data reductionists examined each event to determine whether it was valid (i.e., whether the event could plausibly be related to the presence of an intersection). Events were also examined to make sure that they resulted in a stop. At the end of this process, 353 events remained (1 crash, 32 near-crashes, and 320 incidents). The peak decelerations for these events were 2.7*g* for the crash, 0.66*g* for the near-crashes, and 0.51*g* for the incidents.

DEVELOP A SET OF BASELINE EVENTS

A software tool was developed to examine the 100-Car database in a systematic fashion to find potential baseline events located near the intersection cluster events. The initial intent was to find eight matched baseline events (with the same driver going through the same intersection) for every intersection cluster event. This would have resulted in approximately 2,800 baseline events. The initial run through the data produced a set of 2,646 potential baseline events. At this point data reductionists examined every potential event using the digital video file and map overlay to make sure that each baseline event followed the same path through the intersection and that the event resulted in a stop. When this reduction process was complete, there were 1,109 validated baseline events. These were examined in further detail and certain variables were reduced in the same way as the rear-end event dataset.

COMPARE INTERSECTION BASELINE AND REAR-END EVENTS

Comparisons between the intersection baseline and rear-end events were based on reduced categorical variables, such as traffic control, lighting, weather, etc. The reduced variables available for comparison included:

- Surface condition (wet or dry)
- Weather
- Lighting (ambient light)
- Travel lanes (number of lanes)
- Traffic flow
- Traffic density
- Alignment
- Traffic control
- Relation to junction
- Locality

- Hands on wheel
- Driver seat belt

For these analyses, only the near-crashes, incidents, and baseline events were considered, since there was only one intersection cluster crash. The environmental characteristics were examined first (surface condition, weather, and lighting). Weather and surface condition showed similar patterns, as exemplified in Figure 30 for weather. In this analysis, near-crashes occurred more frequently in worse weather, while incidents and baseline events were nearly identical in their distribution across weather types. Figure 31 shows a similar pattern for lighting. Again, the incident and baseline event distributions are very similar for various levels of ambient light, while on a percentage basis, almost twice as many near-crashes occurred in the darkness conditions.

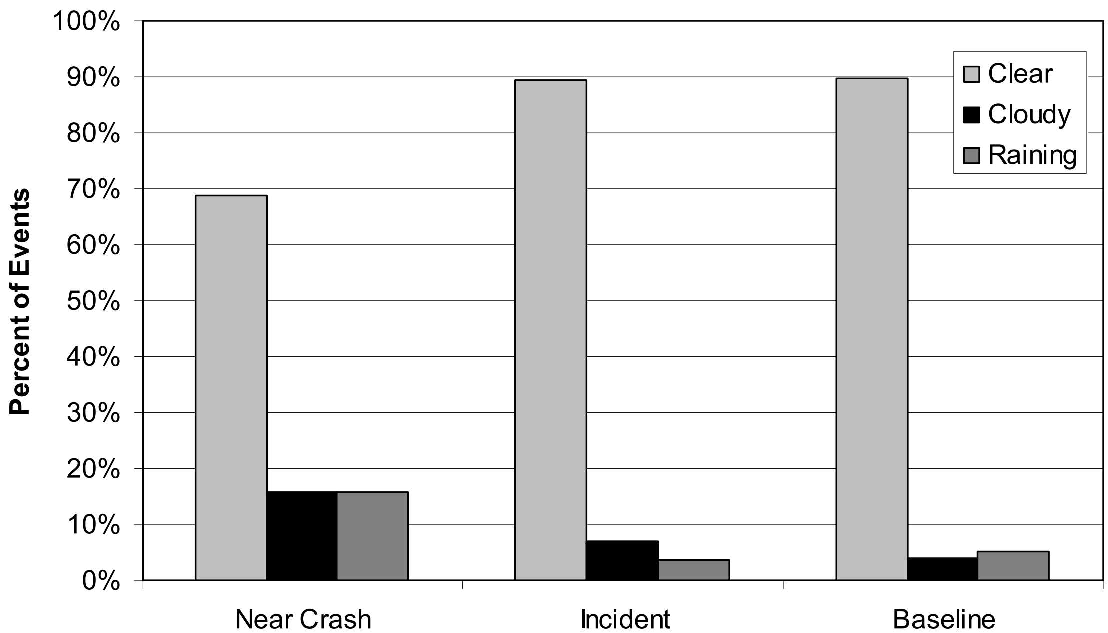

Figure 30. Distribution of weather conditions for near-crashes (N=32), incidents (N=320), and baseline events (N=1,102) occurring at intersection cluster locations.

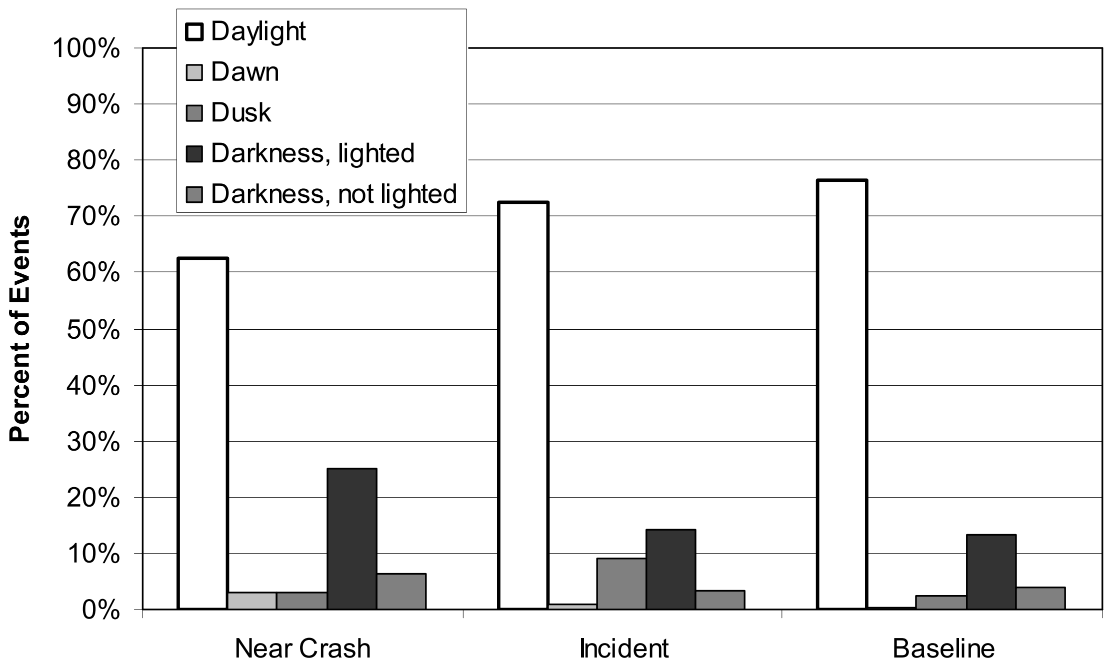

Figure 31. Distribution of lighting conditions for near-crashes (N=32), incidents (N=320), and baseline events (N=1,102) occurring at intersection cluster locations.

The traffic and roadway characteristics were examined next (travel lanes, traffic flow, traffic density, alignment, traffic control, relation to junction, and locality). The number of travel lanes and traffic flow variables did not show any distinct differences between near-crashes, incidents, and baseline events. The traffic flow variable showed that for the two most common categories (flow with some restrictions and stable flow, more restricted speed and maneuverability), approximately 75 percent of baseline events occurred in the less restricted traffic flow situation (flow with some restrictions), while only about 45 percent of near-crashes and 50 percent of incidents occurred in this traffic density condition. Approximately one-third of the near-crashes and incidents occurred in the stable flow, more restricted speed and maneuverability condition, as compared to only about 15 percent of the baseline events. As shown in Figure 32, heavier traffic density at or near intersections thus appears to be conducive to the occurrence of near-crashes and incidents.

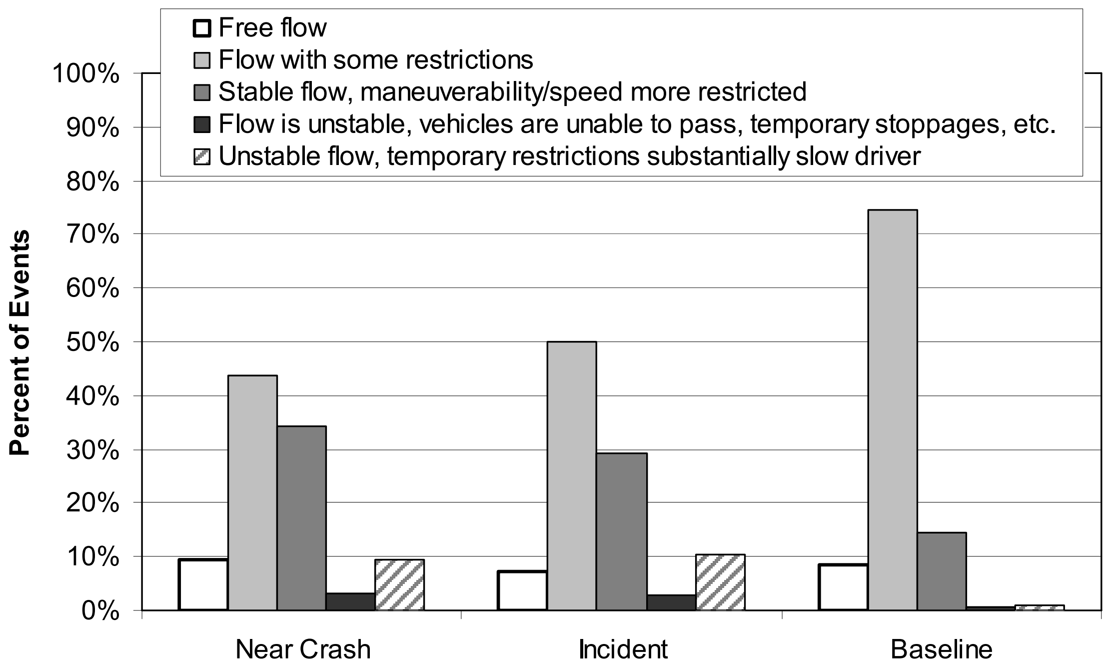

Figure 32. Distribution of traffic density conditions for near-crashes (N=32), incidents (N=320), and baseline events (N=1,102) occurring at intersection cluster locations.

For roadway alignment, 94 percent of both the incidents and baseline events occurred on straight, level sections, with 5 percent occurring on curve, level sections. For near-crashes, 84 percent occurred on straight level sections, and 16 percent on curve, level sections. The traffic control device variable turned out not to be directly comparable, because the near-crash and baseline event data were reduced with regard to a traffic control device being relevant to the event, while the baseline cases were reduced with regard to the traffic control device for the intersection of interest. However, 95 percent of baseline events occurred at intersections with stop lights, indicating their prevalence in the intersection clusters for the near-crashes and baseline events as well. The relation to junction variable was also not directly comparable due to differences in data reduction strategies. For locality, the biggest difference was that 25 percent of baseline events occurred in open country, while fewer than 10 percent of near-crashes and incidents occurred in open country.

The final categorization variables concerned driver behavior (hands on wheel and seat belt usage). No major differences or interesting patterns were observed for the hands on wheel variable. However, differences were observed for seat belt usage, as shown in Figure 33. As event severity increased, the observed use of a lap/shoulder belt decreased. For example, shoulder/lap belt use was observed for nearly 80 percent of baseline events, nearly 70 percent of incidents, and only slightly more than half of near-crashes. No belt use was observed in almost 30 percent of near-crashes, but only in about 15 percent of incidents and baseline events.

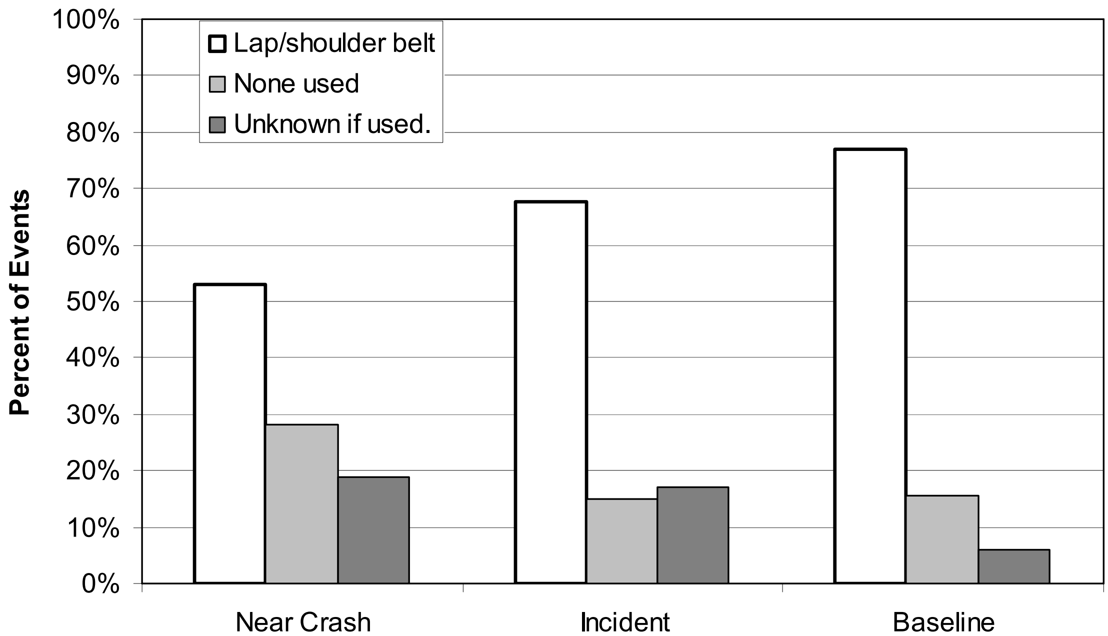

Figure 33. Distribution of seat belt usage for near-crashes (N=32), incidents (N=320), and baseline events (N=1,102) occurring at intersection cluster locations.

SUMMARY

Key points from the intersection cluster braking behavior analysis include:

- A set of baseline intersection approaches was used, based on 50 observed intersection clusters. There were 32 near-crashes, 320 incidents, and 1,102 baseline events in the final dataset used for this question.
- Some of the reduced categorical variables appear to be associated with higher severity, including poor weather, darkness, reduced traffic flow, curved sections of road near the intersection, location away from open countryside, and decreased use of a lap/ shoulder belt.

QUESTION 9: CHARACTERIZATION OF REAR-END EVENTS

What are the influences of traffic, roadway environment, ambient light, and other contributing factors on the risk of rear-end events? What was the distribution of locations of rear-end events (e.g., intersections, freeway junctions, mid-block, etc.)?

This question is intended to provide further clarification regarding the circumstances under which rear-end crash and near-crash events take place, and identification of factors contributing to these incidents. It addresses external roadway, environmental, and weather factors, as well as driver state and vehicle factors. Similar analyses have been undertaken over the years using major available crash databases (e.g., NASS CDS, GES, FARS). Many of these analyses rely on police reports or accident reconstruction and are limited in the amount of detail provided. The 100-Car data affords an opportunity to verify and expand upon this work using detailed crash data records. The literature suggests, for example, that most rear-end crashes occur during daylight hours on dry roads (e.g., Misener, Tsao, Song, and Steinfeld, 2000) with driver inattention serving as a major precipitating factor. Where possible, the current analysis was compared to these previous findings. This information was analyzed in detail, providing insights on how events unfold over time and contribute to the event.

This analysis focuses on rear-end crashes, near-crashes, and incidents and provides descriptive information relating to contributing event factors including:

- Driver sex and age as compared to national statistics and as compared to representation in study.
- Precipitating event.
- Weather (clear, raining, snowing, fog, etc.).
- Roadway surface condition (e.g., dry, wet, icy, etc.).
- Environmental light (dawn, daylight, dusk, darkness, etc.).
- Roadway alignment (straight, curve, grade, etc.).
- Interchange area (intersection, non-intersection, entrance/exit ramp, etc.).
- Locality (residential, school, etc.).
- Traffic flow and traffic density.
- Vehicle contributing factors (e.g., tires, brake system, etc.). *Note - none of the events were coded as due to vehicle contributing factors, so this analysis is not presented.*
- Vehicle maneuver (e.g., going straight, changing lanes, etc.).
- Driver physical/mental impairment.
- Driver distraction (eating, cell phone, passenger in vehicle, external distraction, etc.). *Note – this question was covered thoroughly in Question 2, so is not repeated here.*

Primary findings for this question from the 100-Car dataset include:

- Male drivers were overrepresented in rear-end crashes, as has been found in previous crash database analyses (61% of participants were male, but they accounted for 75% of rear-end crashes). This equates to males being 1.2 times more likely to be involved in a rear-end crash than females. However, females were involved in 50 percent of the near-crashes, even though only 39 percent of participants were female (thus females were 1.3 times as likely to be involved in a near-crash).

- Drivers in the 25- to 34-year-old age group were 1.9 times as likely to be involved in rear-end crashes as other age groups (17% of participants were in this age group, but they accounted for 33 percent of rear-end crashes).
- More specifically, 25- to 34-year-old males were overrepresented in rear-end crashes (17% of participants were 25- to 34-year-old males, but they accounted for 29% of rear-end crashes). This sex/age group was 1.7 times as likely to be involved in rear-end crashes than other sex/age groups, which accounts for much of the age and sex overrepresentation discussed in the previous two bullets.
- There were 44 different precipitating event categories in the dataset, but most events fell into 22 categories concerning lead- and subject-vehicle kinematics and lane changes. Altogether, 100 percent of crashes, 97 percent of near-crashes, and 98 percent of incidents are covered in these 22 precipitating event categories.
- Weather analysis results indicated that most rear-end events occur in clear weather conditions, as had been found in previous studies. However, a conflict with a lead or following vehicle may be more likely to result in a crash or near-crash when an unfavorable weather condition is present.
- Although most events occurred on dry roads, a conflict with a lead or following vehicle occurring on wet roads was more likely to result in a crash or near-crash than was a conflict occurring on dry roads, which was more likely to result in an incident.
- There was no clear influence of environmental light on event severity, although most events occurred in the daylight.
- Most events occurred on straight, level roads. However, when a conflict with a lead or following vehicle occurred on a curved section of road rather than on a straight section of road, it was increasingly likely to result in a near-crash or crash rather than an incident.
- Conflicts that occurred in intersections, intersection-related areas, or entrance/exit ramp locations were more likely to result in crashes than those occurring in non-junction locations. Over 60 percent of crashes occurred in intersection and intersection-related locations, while more than 60 percent of both near-crashes and events occurred in non-junction locations.
- Conflicts occurring in business/industrial locations were more likely to result in a crash than were conflicts occurring in open country and residential areas. However, business/industrial was the most common location type for all event severities.
- Over 60 percent of the rear-end crashes occurred in what would be considered the best two traffic flow and density situations: free flow and flow with some restrictions.
- For crashes, the most common pre-incident maneuver was decelerating in traffic lane, which accounted for 44 percent of the rear-end crashes. For both near-crashes and incidents, on the other hand, the most common maneuver was going straight at a constant speed, at about 44 percent for each.
- Incidents are not always good predictors of crashes. In examining the factors explored in this question, near-crashes are generally much more closely aligned with crashes than are incidents.

Chi-square analyses of the frequency tables showed significant results in every case. In some cases only near-crashes and incidents could be included in the Chi-square analysis because the expected frequency of cells in the crash categories was less than five. The Chi-square results are not shown because they were significant in every case.

DRIVER SEX AND AGE

The 100-Car Study report has details of the exposure rate for age and gender in terms of rear-end events per million vehicle miles traveled (MVMT). The current analyses do not repeat these analyses, but rather place the number of events in context with the representation of age and gender in the database. In order to eliminate unknown ages and genders, only primary drivers are represented in these analyses. As can be seen in Table 26, there were 6,402 events recorded for primary drivers. Of these, 54 percent were recorded for males and 46 percent for females. In terms of representation in the study, 61 percent of the primary drivers were male and 39 percent were female. Males seemed to be somewhat overrepresented in crashes (75% of crashes though they were only 61% of drivers) and underrepresented in near-crashes (50% of near-crashes had male drivers) and incidents (54% of incidents had male drivers). Wiacek and Najm (1999) analyzed the 1996 GES database for age and gender factors for rear-end crashes and likewise found that males were somewhat overrepresented in rear-end crashes (males constituted 53% of the driving population, yet were involved in 60% of all rear-end crashes). There are no national statistics on near-crashes and incidents for comparison purposes.

Table 26. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events by Sex and Severity. Items in gray indicate overrepresentation as compared to presence in the population.

Sex	Severity (N, %)			
	Crash	**Near-Crash**	**Incident**	**Total**
Female (39%)	6 25.0%	207 50.2%	2,728 45.7%	2,941 45.9%
Male (61%)	18 75.0%	205 49.8%	3,238 54.3%	3,461 54.1%
Total	24 100.0%	412 100.0%	5,966 100.0%	6,402 100.0%

The age distribution of events for primary drivers is shown in Figure 34. Tables A1 and A2 in Appendix A present the distribution and percentage of events by age group. Note that drivers under the age of 24 made up 35 percent of the driver pool, and were involved in 33 percent of the rear-end crashes, so did not seem to be over-represented in crashes. However, these youngest two driver groups were involved in 51 percent of the near-crashes and 46 percent of the incidents. For the oldest driving group, those aged 55 and over made up 12 percent of the driver pool and were involved in 13 percent of the crashes, 8 percent of the near-crashes, and 7 percent of the incidents.

Wiacek and Najm (1999) also analyzed the 1996 GES database for age and found that drivers less than 24 years old were overly involved in rear-end crashes, in that they represent 21 percent of all drivers yet were involved in 30 percent of all rear-end crashes. This finding was not supported by the 100-Car database in terms of crashes, but was supported for near-crashes and incidents. Wiacek and Najm found that drivers over age 64 were under-involved in rear-end crashes; this age group represented 13 percent of all licensed drivers, yet were involved in only 6 percent of all rear-end crashes. This finding was again supported for near-crashes and incidents, but not for crashes (keeping in mind that the oldest age group for the 100-Car Study was 55+ years rather than 64+ years).

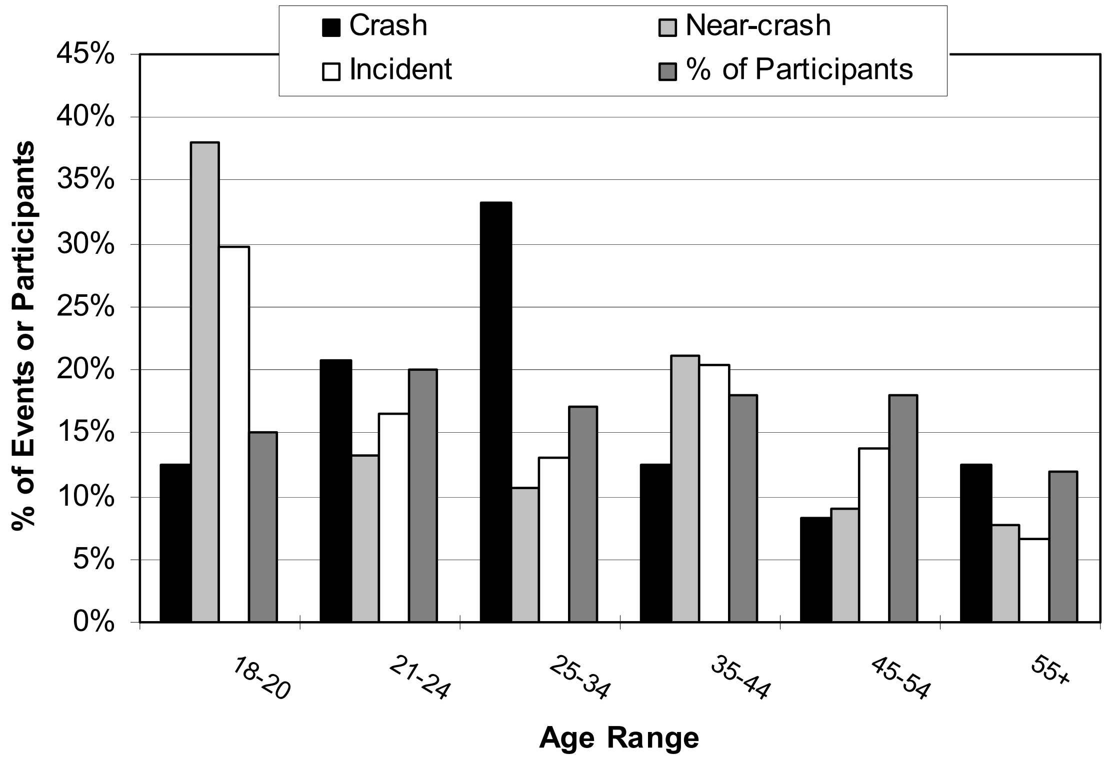

Figure 34. Age Distribution of Events for the Primary Drivers in the 100-Car Study.

Figure 35 presents the age and gender distribution of events for the 100-Car primary drivers. Table A3 presents the age and gender distribution for rear-end crashes, near-crashes, and incidents for primary drivers, while Table A4 presents the same information in percentage form. Note that there were age-dependent gender differences; for example, females age 24 and younger made up 18 percent of the participants, but accounted for 21 percent of the total crashes, 32 percent of the near-crashes, and 31 percent of the incidents. For males, the ages of 25 to 44 seemed to be overrepresented for crashes; this group made up 26 percent of participants, but accounted for 42 percent of crashes. Males 18 to 24 years old made up 16 percent of participants and accounted for 19 percent of near-crashes. For incidents, males 18 to 20 years old made up 6 percent of participants and accounted for 8 percent of incidents, while males were underrepresented in every other age group.

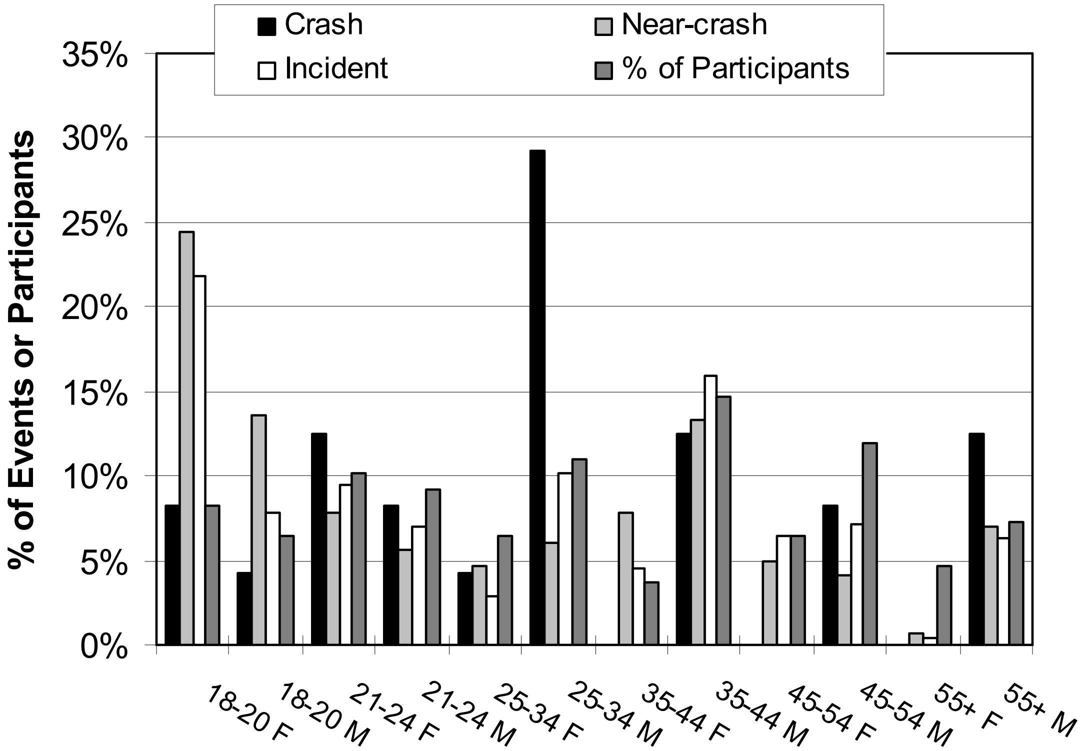

Figure 35. Age by Sex Distribution of Events for 100-Car Study Primary Drivers.

PRECIPITATING EVENT

There were 44 different precipitating events categories coded in the 7,024 events in the full dataset (Table A5 in Appendix A). Of these, most fell into the nine categories concerning lead vehicle and subject vehicle kinematics such as *LV* or *SV decelerating, stopped ≤ 2 s, stopped > 2 s, accelerating,* and *moving at a slower constant speed.* These nine categories accounted for 96 percent of crashes, 77 percent of near-crashes, and 86 percent of incidents. Most of the remaining events were lane-change events. When the 13 lane-change categories are added, 100 percent of crashes, 97 percent of near-crashes, and 98 percent of incidents are covered in these 22 precipitating event categories.

Table 27 shows the distribution and percentage for the nine LV and SV kinematics categories. Nearly 60 percent of crashes fell into only two categories: *LV stopped ≤ 2 s* and *LV stopped > 2 s*. Altogether, 22 of 27 crashes occurred with a stopped lead vehicle (81%). This indicates that the stopped-lead-vehicle case may be the most important in preventing rear-end crashes. Only 15 percent of crashes (4 of 27) occurred when the lead vehicle was decelerating (whether that lead vehicle was the subject vehicle or a vehicle in front of the subject vehicle). This is 50 percent lower than the figures reported by Knipling, Wang, and Yin (1993), who found that the lead vehicle was moving in 30 percent of rear-end crashes. The final crash resulting from a conflict with a lead or following vehicle was a lane-change crash (4%). For the near-crashes, 87 percent occurred for the three categories of *LV decelerating, LV stopped > 2 s,* and *LV stopped ≤ 2 s*, while the same three categories accounted for 93 percent of incidents. The high number of

LV decelerating near-crashes and incidents, with no crashes for this category, may indicate that drivers have an easier time detecting the closing rate to a decelerating lead vehicle than to a stopped lead vehicle.

Table 27. Distribution and Percentage of *Conflict with LV* and *Conflict with FV* Events by Severity and Nine LV and SV Kinematics Precipitating Event Categories.

Precipitating Event	Severity (N, %)			
	Crash	**Near-Crash**	**Incident**	**Total**
LV Decelerating	0 0%	172 49.7%	2,794 49.7%	2,966 49.5%
LV Stopped > 2 s	8 30.8%	44 12.7%	1,331 23.7%	1,383 23.1%
LV Stopped ≤ 2 s	7 26.9%	85 24.6%	1,089 19.4%	1,181 19.7%
LV Accelerating	0 0%	1 0.3%	12 0.2%	13 0.2%
LV Slower Constant Speed	0 0%	6 1.7%	131 2.3%	137 2.3%
SV Decelerating	4 15.4%	22 6.4%	153 2.7%	179 3.0%
SV Stopped > 2 s	4 15.4%	0 0%	48 0.9%	52 0.9%
SV Stopped ≤ 2 s	3 11.5%	16 4.6%	46 0.8%	65 1.1%
SV Slower Constant Speed	0 0%	0 0%	18 0.3%	18 0.3%
Total	26 100%	346 100%	5,622 100%	5,994 100%

Tables A6 and A7 in Appendix A present the distribution and percentage of lane-change precipitating events. When these 13 categories are added to the nine kinematics categories, over 95 percent of the total events are covered in only 22 of the 44 total kinematics categories. There was only one lane-change rear-end crash, and it was of the type *POV lane change - left other*. For near-crashes, the top three categories were *POV lane change - left in front of SV; POV lane change - right in front of S;* and *SV lane change - left in front of vehicle*. Combined, these three categories accounted for 86 percent of lane-change near-crashes. The same three categories also dominated the incident event type, accounting for 68 percent of the lane-change incidents. A fourth dominant category for incidents was *SV lane change - right in front of vehicle*; when this is added in, these four categories account for 84 percent of lane-change incidents.

Perhaps the most interesting finding for the precipitating event analysis is the degree to which the majority of crashes, near-crashes, and incidents could be accounted for by just a few precipitating event categories. There were 44 categories coded for at least one crash, near-crash, or incident. However, 100 percent of the crashes occurred in just 6 of these categories. For near-crashes, 96 percent occurred in just 10 categories, while for incidents, 96 percent occurred in just 11 categories. These top categories are summarized below in Table 28, and provide guidance as to the type of countermeasures that can be used to prevent conflicts with lead and following vehicles.

Table 28. Top precipitating event categories for crashes, near-crashes, and incidents.

Crashes (27 total; 100% in 6 categories)		
Precipitating Event	**Number**	**Percentage**
LV Stopped > 2 s	8	29.6%
LV Stopped ≤ 2 s	7	25.9%
SV Decelerating	4	14.8%
SV Stopped > 2 s	4	14.8%
SV Stopped ≤ 2 s	3	11.1%
POV lane change - left other	1	3.7%
Near-Crashes (450 total; 96% in 10 categories)		
Precipitating Event	**Number**	**Percentage**
LV Decelerating	172	38.2%
LV Stopped ≤ 2 s	85	18.9%
LV Stopped > 2 s	44	9.8%
POV lane change - right in front of SV	34	7.6%
POV lane change - left in front of SV	34	7.6%
SV Decelerating	22	4.9%
SV Stopped ≤ 2 s	16	3.6%
SV lane change - left in front of vehicle	10	2.2%
SV lane change - right in front of vehicle	7	1.6%
LV Slower Constant Speed	6	1.3%
Incidents (6,547 total; 96% in 11 categories)		
Precipitating Event	**Number**	**Percentage**
LV Decelerating	2,794	42.7%
LV Stopped > 2 s	1,331	20.3%
LV Stopped ≤ 2 s	1,089	16.6%
SV lane change - left in front of vehicle	212	3.2%
POV lane change - right in front of SV	203	3.1%
SV Decelerating	153	2.3%
POV lane change - left in front of SV	145	2.2%
SV lane change - right in front of vehicle	135	2.1%
LV Slower Constant Speed	131	2.0%
SV Stopped > 2 s	48	0.7%
SV Stopped ≤ 2 s	46	0.7%

WEATHER

Weather seemed to play a greater role in crashes than in near-crashes and incidents. As shown in Figure 36 and in Table A8, close to 60 percent of crashes happened in clear weather, while 80 percent of near-crashes happened in clear weather and close to 90 percent of incidents occurred in clear weather. Cloudy conditions accounted for 19 percent of crashes, 12 percent of near-crashes, and 7 percent of incidents. Rain was present for 19 percent of crashes, 8 percent of near-crashes, and 5 percent of incidents. These results indicate that a conflict with a lead or following vehicle may be more likely to result in a crash or near-crash when an unfavorable weather condition is present.

Snow accounted for 3.7 percent of crashes, and less than 1 percent of near-crashes and incidents. Knipling, Wang, and Yin (1993a) found that 78.8 percent of crashes occurred during dry weather, 18.0 percent occurred during rain, and 1.9 percent occurred during snow. When clear and cloudy weather conditions are combined for the 100-Car rear-end crashes, 78 percent occurred in dry conditions, 19 percent in rain, and 4 percent in snow, which is in close agreement with the Knipling et al. (1993a) findings. In another analysis, Knipling, Mironer, Hendricks, Tijerina, Everson, Allen, and Wilson (Knipling et al., 1993b) reported that 3.4 percent of rear-end crashes occurred in snow or ice, which is also in close agreement with the findings of this study.

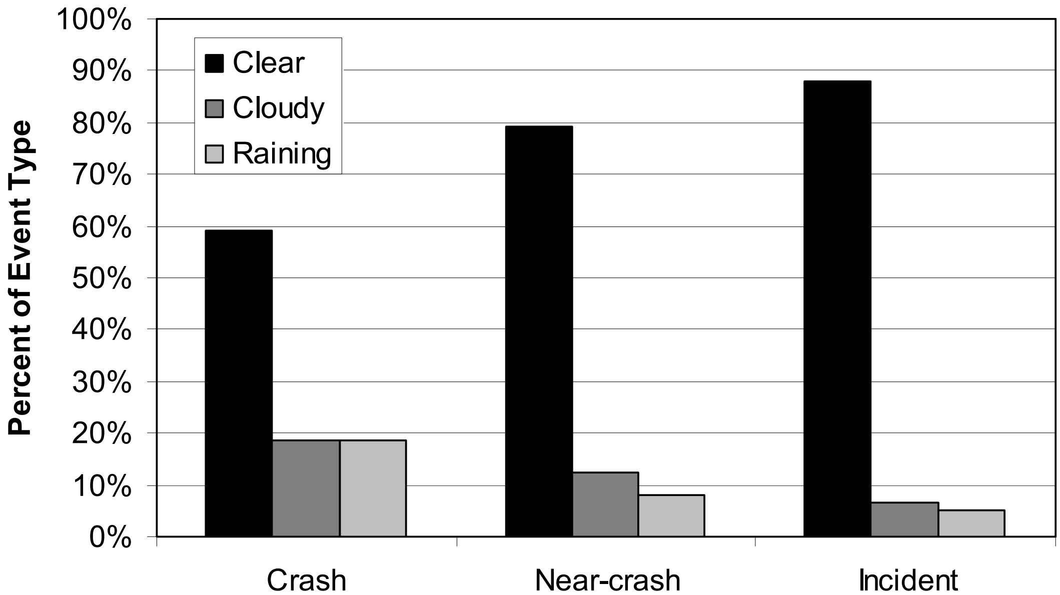

Figure 36. Percentage of *Conflict With LV* and *Conflict With FV* Events by Weather.

The weather categories were crossed with the nine LV and SV kinematics precipitating event categories (Tables A9 and A10 in Appendix A). It was hoped that this breakdown would provide insight as to whether certain precipitating events are more likely to occur in certain weather conditions, but no obvious pattern appears in the data.

ROADWAY SURFACE CONDITION

Table 29 presents the 100-Car findings for roadway surface condition. As was the case for weather, a conflict with a lead vehicle occurring on wet roads was more likely to result in a crash or near-crash than was a conflict occurring on dry roads, which was more likely to result in an incident. Figure 37 shows the trends for both dry and wet roads; not surprisingly, they are closely aligned with the weather trends. In terms of crashes, Knipling et al. (1993a) reported that the roadway surface condition was dry in 72 percent of rear-end crashes, as compared to 67 percent for these data. Campbell, Smith, and Najm (2003) reported that the roadway surface was wet in 18 percent of rear-end crashes, while 30 percent of the 100-Car Study rear-end crashes occurred on wet roadways.

Table 29. Distribution of *Conflict With LV* and *Conflict With FV* Events by Roadway Surface Condition and Severity.

	Severity (N, %)			
Roadway Surface Condition	**Crash**	**Near-crash**	**Incident**	**Total**
Dry	18 66.7%	394 87.6%	6,022 92.0%	6,434 91.6%
Wet	8 29.6%	56 12.4%	509 7.8%	573 8.2%
Snowy	1 3.7%	0 0%	10 0.2%	11 0.2%
No analyzed data	0 0%	0 0%	5 0.1%	5 0.1%
Other	0 0%	0 0%	1 0.0%	1 0.0%
Total	27 100.00%	450 100.00%	6,547 100.00%	100.00%

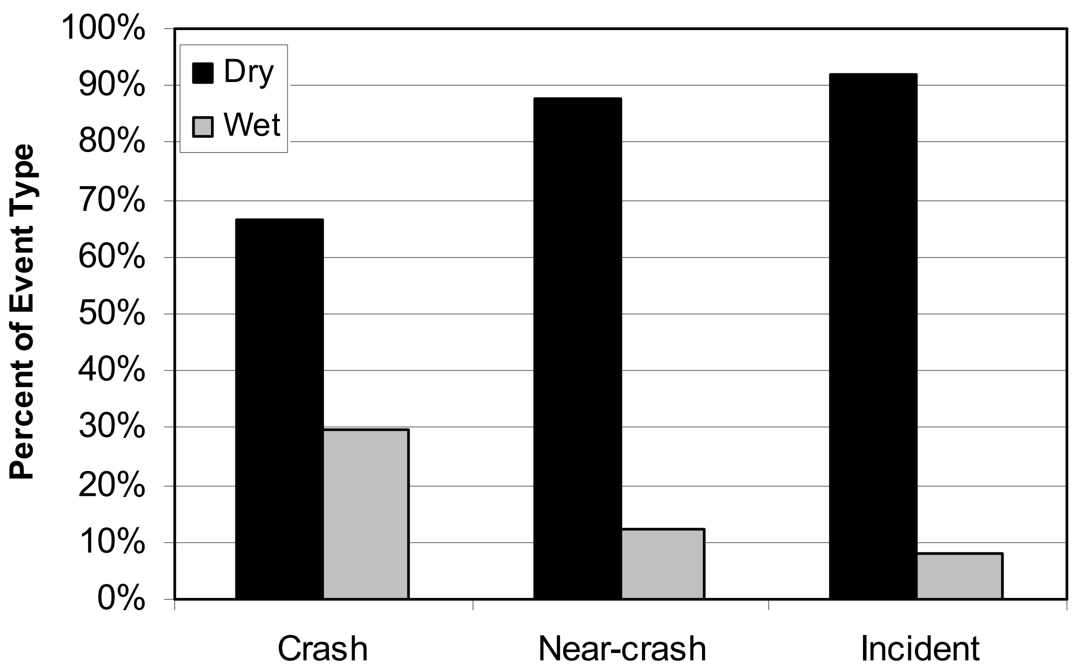

Figure 37. Percentage of *Conflict With LV* and *Conflict With FV* Events by Surface Condition.

ENVIRONMENTAL LIGHT

Environmental light conditions at the time of a LV or FV event is of interest because the worst viewing conditions for rear brake lamps occur in daylight when contrast is lowest. As seen in Table 30 and Figure 38, 74 percent of crashes, 65 percent of near-crashes, and 75 percent of incidents occurred in daylight. The next most frequent category was dark but lighted, with 15 percent of crashes, 18 percent of near-crashes, and 13 percent of incidents. Again, in artificially lit conditions, contrast between the brake lamps and the surround is likely to be lower than in dark-but-not-lighted conditions. No clear influence of environmental light on event severity can be seen in Figure 38.

It is unknown what proportion of time was spent driving in various light conditions during the study. However, the 2001 National Household Travel Survey (U.S. Department of Transportation, 2003) showed that 77 percent of household daily trips began during the hours of 6 a.m. to 6 p.m., and that 23 percent began from 6 p.m. to 6 a.m. If we consider these hours to roughly correspond to the hours of daylight and dark, and if we further assume that the 100-Car Study drivers followed a similar pattern, then the crashes and incidents show almost the exact same proportions, while near-crashes are overrepresented at night (35% of near-crashes occurred in other than daylight, while 23% of travel is assumed to have happened during this time).

Table 30. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events by Environmental Light and Severity.

Environmental Light	Severity (N, %)			
	Crash	Near-Crash	Incident	Total
Daylight	20 74.1%	293 65.1%	4,890 74.7%	5,203 74.1%
Dark, lighted	4 14.8%	80 17.8%	863 13.2%	947 13.5%
Dusk	1 3.7%	41 9.1%	460 7.0%	502 7.1%
Dark, not lighted	1 3.7%	27 6.0%	250 3.8%	278 4.0%
Dawn	1 3.7%	9 2.0%	81 1.2%	91 1.3%
No analyzed data	0 0%	0 0%	3 0.0%	3 0.0%
Total	27 100.0%	450 100.0%	6,547 100.0%	7,024 100.0%

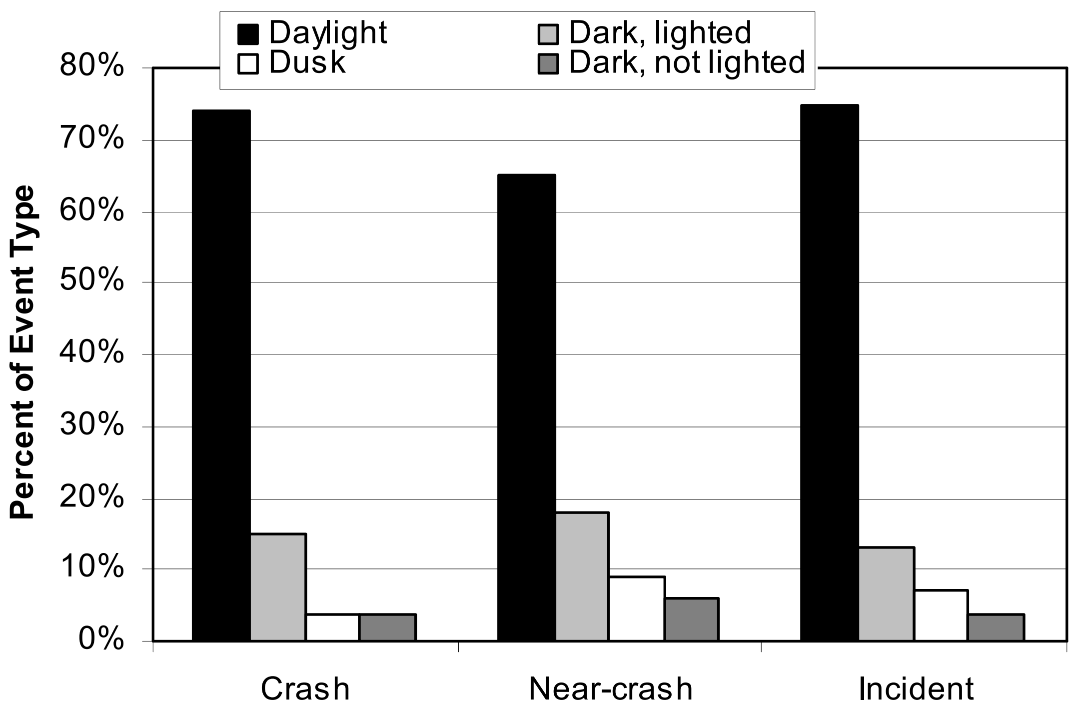

Figure 38. Percentage of *Conflict With LV* and *Conflict With FV* Events by Environmental Light.

For rear-end crashes, Knipling et al. (1993a) found that 76.5 percent of crashes occurred during daylight, as compared to 74.1 percent for the 100-Car Study, while 14.2 percent occurred under “dark but lighted” conditions as compared to 14.8 percent for the 100-Car Study. Again, these values are quite consistent, especially considering the fact that the Knipling et al. (1993a) report considered 1990 GES and CDS data collected from police accident reports, while the 100-Car Study was conducted in a limited geographic area (primarily northern Virginia, but also the Washington, DC, metropolitan area, with occasional data from portions of Maryland near Washington, DC) in 2003-04 with environmental data taken from video analysis. Campbell, Smith, and Najm (2003) reported that the lighting conditions were dark in 22 percent of the rear-end crashes studied, while in the 100-Car Study, 26 percent of rear-end crashes occurred in other-than-daylight conditions.

When light condition is crossed with weather, about 60 percent of crashes happened in daylight clear and daylight cloudy conditions. This finding generally agrees with Najm, Koziol, Tijerina, Pierowicz, and Hendricks (1994) who found that 57 percent of all crashes occurred in this combination of light and weather. In the 100-Car Study, 58 percent of rear-end near-crashes occurred in daylight clear or daylight cloudy conditions, while 71 percent of incidents happened under these conditions.

Tables A11 and A12 in Appendix A present the distributions and percentage for kinematics precipitating events crossed with environmental light conditions. It was hoped that this would provide insight as to the role of brake light visibility for various kinematics conditions. Some of the crash situations are worth noting. For *LV stopped > 2 s*, exactly half the crashes occurred in daylight and half in other than daylight, thus indicating that this type of crash is overrepresented in dark conditions (assuming the same travel patterns previously discussed). Thus a vehicle that is stopped for more than 2 s is equally likely to be struck in the day and at night, even if more travel occurs during the day. For *LV stopped < 2 s, SV stopped < 2 s,* and *SV decelerating*, all but one crash (93 percent) occurred during the daytime, indicating that these types of crashes in which the lead vehicle is slowing or has just stopped are more likely to occur during the day relative to the amount of travel done during the day.

ROADWAY ALIGNMENT

As shown in Figure 39, when a conflict with a lead or following vehicle occurs on a curve rather than on a straight section of road, it is increasingly likely to result in a near-crash or crash rather than an incident. Table A13 in Appendix A presents all of the categories for roadway alignment. The topography in the area where the 100-Car Study was conducted is relatively level, with over 98 percent of events occurring on roads marked as level (91% straight level and 7% curve level). Knipling at al. (1993a) found that only 8.2 percent of rear-end crashes occurred on a curve or hillcrest, as opposed to the 22 percent found in this study. The difference may be attributable to the topography of the study area (curvy roads are common, even though hills are not) as compared to other parts of the country (in many areas of the country, roads are laid out in very straight, regular grid patterns).

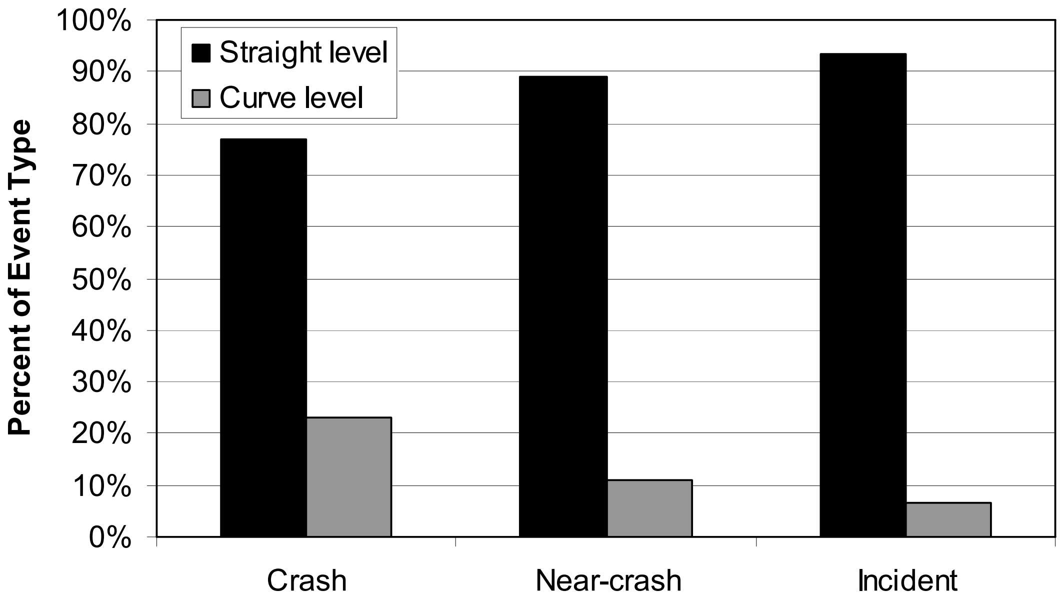

Figure 39. Percentage of *Conflict With LV* and *Conflict With FV* Events by Straight- and Curved-Road Alignment.

RELATION TO JUNCTION

The rear-end crashes were fairly evenly divided in terms of relation to junction. One-third occurred in non-junction areas, 30 percent were considered intersection-related, and about 19 percent each occurred at intersections or on entrance/exit ramps (Tables A14 and A15). As shown in Figure 40, conflicts that occurred in intersection, intersection-related, or entrance/exit ramp locations were more likely to result in crashes than those occurring in non-junction locations. Knipling, Wang, and Yin (1993a) found that 54.9 percent of all rear-end crashes were intersection, intersection-related, or driveway/alley access-related stopped-lead-vehicle crashes, whereas 48.1 percent of the 100-Car rear-end crashes fell into these three categories.

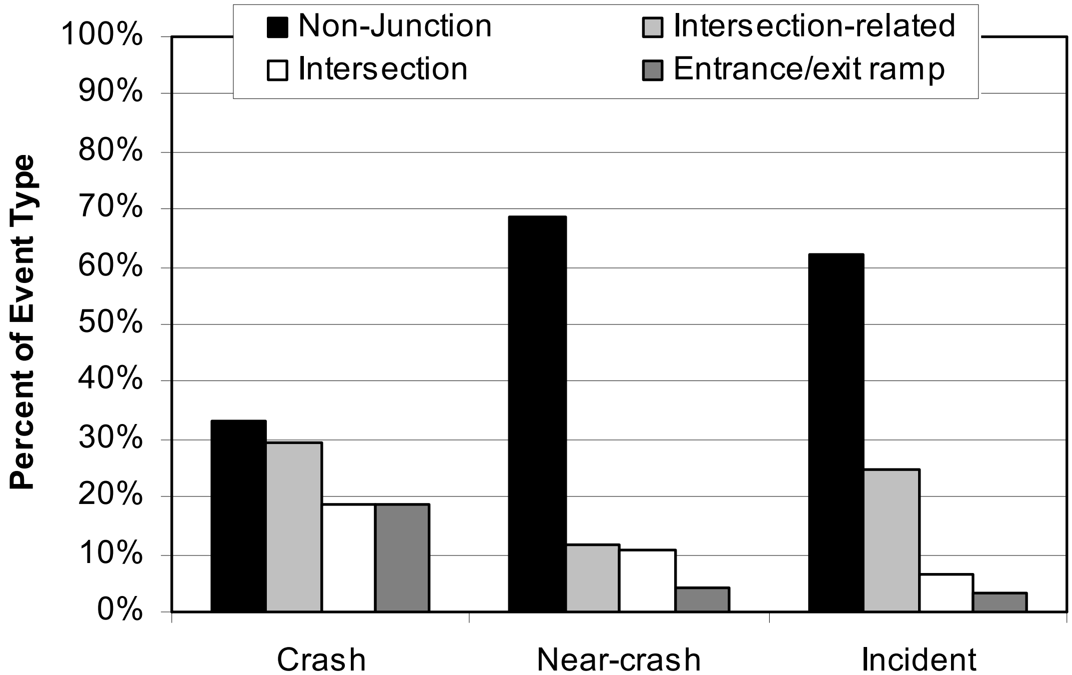

Figure 40. Percentage of *Conflict With LV* and *Conflict With FV* Events by Relation to Junction.

LOCALITY

The nature of the locality where the event occurred was coded in the 100-Car data reduction process. Figure 41 demonstrates that conflicts occurring in business/industrial locations were more likely to result in a crash than were conflicts occurring in open country and residential areas. Close to 60 percent of rear-end crashes were coded as occurring in business/industrial locations, with relatively few crashes occurring on interstates, in open country, in residential areas, or in construction zones (Tables A16 and A17). The distributions were more even for near-crashes and incidents, but the rank ordering of location was the same regardless of severity level. In decreasing order, they were business/industrial, interstate, open country, residential, and construction zone.

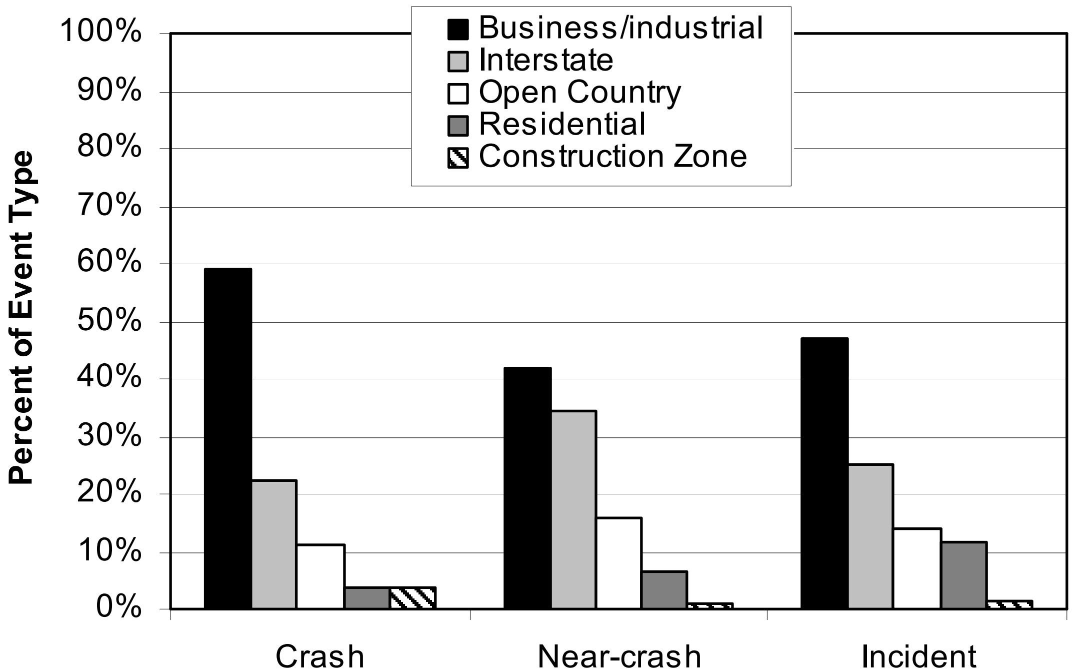

Figure 41. Percentage of *Conflict With LV* and *Conflict With FV* Events by Locality.

TRAFFIC FLOW/DENSITY

The following categories and definitions were used to classify events according to the traffic flow and traffic density. These categories correspond to Levels of Service (LOS) A through F used in highway design.

- Free flow.
- Flow with some restrictions.
- Stable flow, more restricted maneuverability, speed: Stable flow, maneuverability, and speed are more restricted.
- Unstable flow, temporary restrictions: Unstable flow, temporary restrictions, substantially slow driver.
- Unstable flow, significant restrictions: Flow is unstable, vehicles are unable to pass, temporary stops, etc.
- Forced traffic flow with low speeds, below-capacity traffic volumes: Forced traffic flow condition with low speeds and traffic volumes that are below capacity. Queues forming in particular locations.

Perhaps the most surprising finding is that over 60 percent of the rear-end crashes occurred in what would be considered the best two traffic situations: free flow and flow with some restrictions. This might indicate that drivers were more often either engaging in distracting behaviors or paying less attention to conditions when they perceived that the traffic conditions were safe. Conversely, when they were in stop-and-go traffic, they may have devoted more attention to conditions and thus been more able to avoid turning conflicts into crashes. For example, 33 percent of crashes occurred in the free-flow condition, a little over 20 percent of the near-crashes occurred in this condition, and less than 10 percent of incidents occurred in free-flow traffic (Figure 42). For near-crashes, the most likely traffic condition was flow with some restrictions, at 33 percent, while for incidents, the same category accounted for 45 percent of the events. Table A18 presents the full results for this analysis.

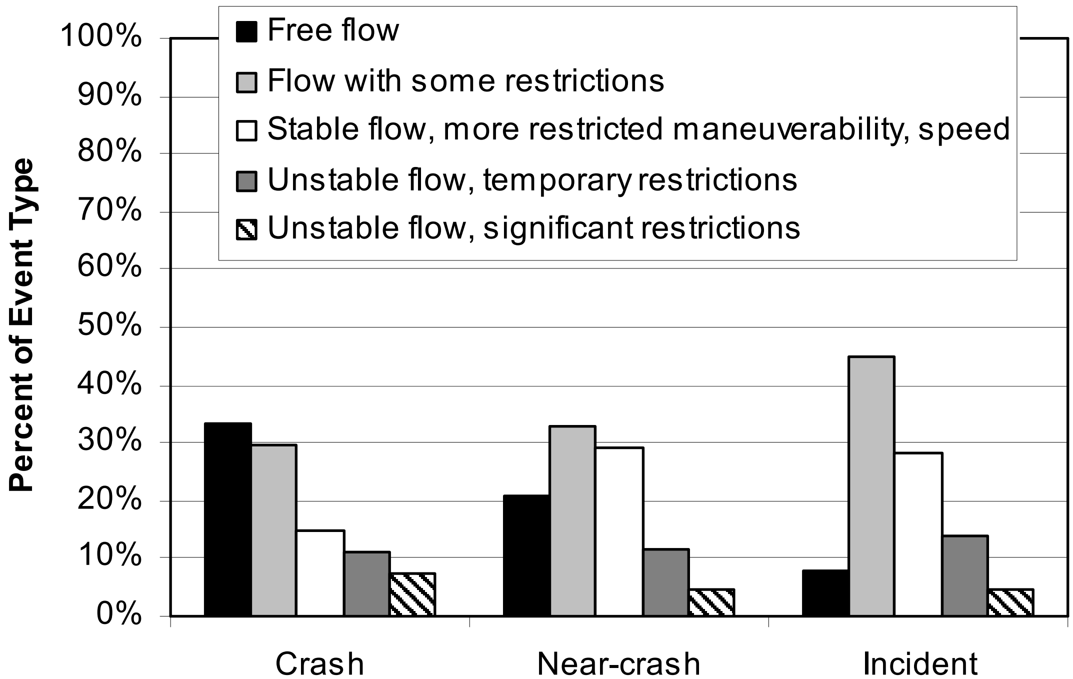

Figure 42. Percentage of *Conflict With LV* and *Conflict With FV* Events by Traffic Flow/Density.

To test the hypothesis regarding driver inattention and distraction with relation to traffic conditions, Table A19 was created to show the number and percentage of events for each traffic condition for which a distraction of some sort was coded. Two-thirds of rear-end crashes were coded with some sort of distraction, as compared to 41 percent of near-crashes and 24 percent of incidents. When the crashes are examined as shown in Figure 43, it is obvious that distraction occurred at fairly constant rates for each of these traffic conditions (63% for flow with some restrictions; 50% for stable flow, more restricted maneuverability, speed; 67% for unstable flow, temporary restrictions; and 67% for free flow). Similar patterns occurred for near-crashes and crashes, with the percentage of events coded with distraction occurring at levels very near the mean level for each traffic condition. Thus the hypothesis that drivers are paying closer attention in more constricted traffic was not supported by this examination of the data.

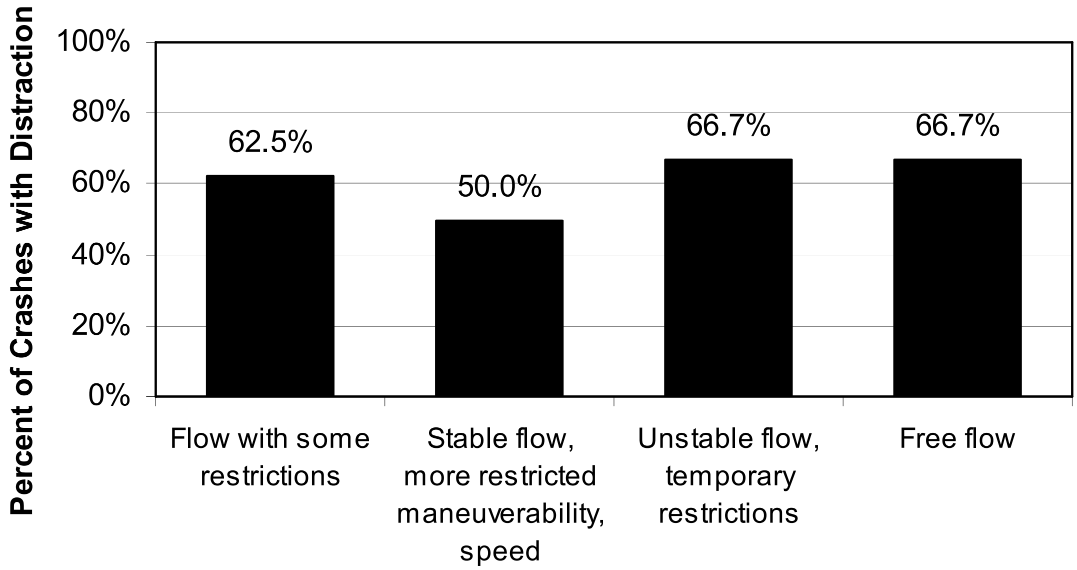

Figure 43. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Crashes For Which a Distraction Was Coded by Traffic Flow/Density.

VEHICLE MANEUVER

The most common pre-incident maneuver for the subject (100-Car) vehicle involved in rear-end crashes was decelerating in traffic lane, which accounted for 44.4 percent of the rear-end crashes (Tables A 20 and 21). For both near-crashes and incidents, on the other hand, the most common maneuver was going straight at a constant speed, at about 44 percent for each. Figure 44 shows this trend as well as the fact that the most common remaining pre-incident maneuvers for crashes were almost equal to one another at about 10 percent each (going straight at constant speed, going straight and accelerating, starting in traffic lane, stopped in traffic lane, and merging). Near-crashes and incidents showed a very similar pattern to one another, with a relatively large percentage occurring when decelerating in traffic lane, going straight and accelerating, and changing lanes. For near-crashes and incidents, the common crash maneuvers of starting in traffic lane, stopped in traffic lane, and merging occurred at insignificant levels.

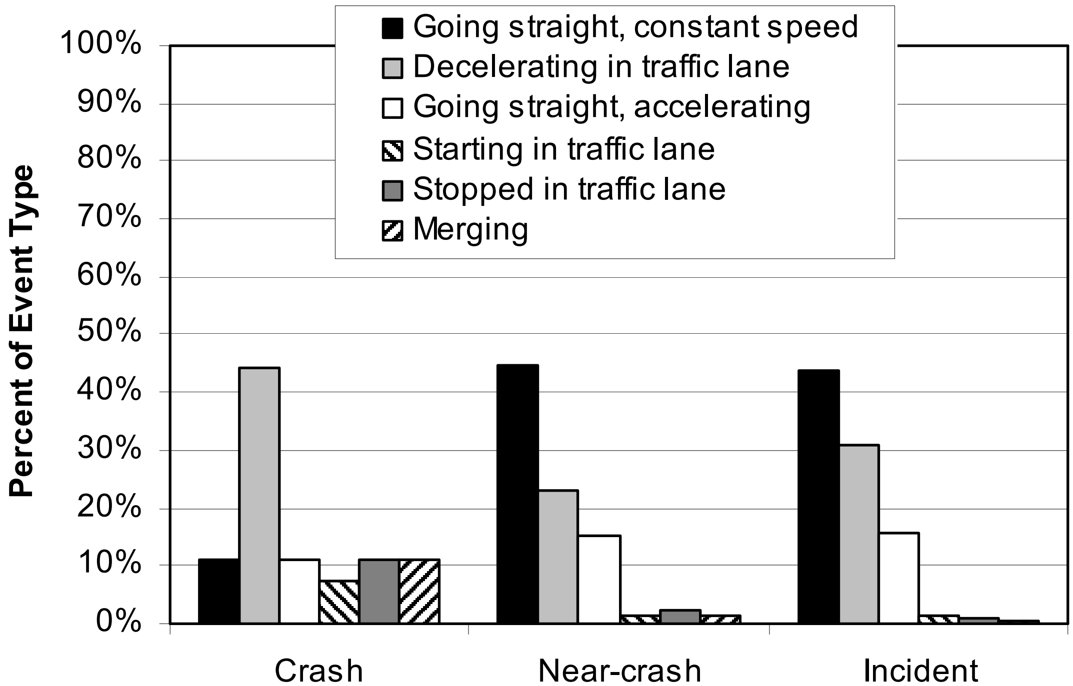

Figure 44. Percentage of *Conflict With LV* and *Conflict With FV* Events by Pre-Incident Maneuver.

In order to determine whether the pre-incident maneuver was considered to be both safe and legal, the maneuver type was crossed with a judgment of maneuver safety and legality. It was hoped that this would provide insight as to whether certain pre-incident maneuvers were more often performed unsafely and/or illegally than were other maneuvers. As seen in Tables A22 and A23 (in Appendix A), 90 to 100 percent of crashes, near-crashes, and incidents for most pre-incident maneuvers were considered to be both safe and legal. The exceptions were:

- The going straight, accelerating maneuver was considered to be unsafe but legal in 33.3 percent of crashes.
- The changing lanes maneuver:
    - Was considered to be unsafe and illegal in 27.9 percent of near-crashes and 12.3 percent of incidents.
    - Was considered to be unsafe but legal in 14 percent of near-crashes and 13.4 percent of incidents.
- The stopped-in-traffic-lane maneuver was considered to be unsafe but legal in 10 percent of near-crashes and unsafe and illegal in another 10 percent of near-crashes.
- The merging maneuver was considered to be unsafe but legal in 33.3 percent of near-crashes and unsafe and illegal in another 16.7 percent of near-crashes.
- Going straight with unintentional drift was considered to be unsafe and illegal in 57.1 percent of incidents.
- Maneuvering to avoid a vehicle was considered to be unsafe and illegal in 50 percent of incidents and unsafe but legal in another 50 percent of incidents.

When only conflicts with a lead vehicle are considered, the most common joint pre-incident maneuvers were:

- LV stopped in traffic lane and FV decelerating (22%, 9%, and 16% of crashes, near-crashes, and incidents, respectively).
- LV stopped in traffic lane and FV accelerating (7%, 6%, 6%).
- LV stopped in traffic lane and FV going straight, constant speed (7%, 14%, 14%).
- LV stopped in traffic lane and FV merging (4%, 0%, 0%).
- LV stopped in traffic lane and FV starting in traffic lane (4%, 1%, 1%).
- LV stopped in traffic lane and FV stopped in traffic lane (4%, 1%, 0%).
- LV other and FV merging (4%, 0%, 0%).
- LV decelerating in traffic lane and FV going straight at constant speed (0%, 15%, 19%).

When only conflicts with a following vehicle are considered, the most common joint pre-incident maneuvers become:

- Both vehicles decelerating in traffic lane (11%, 3%, and 2% of crashes, near-crashes, and incidents, respectively).
- Lead vehicle decelerating and following vehicle going straight, constant speed (4%, 2%, 1%).
- LV decelerating and FV other (4%, 0%, 0%).
- LV decelerating and FV unknown (4%, 0%, 0%).
- LV going straight, accelerating and FV going straight, constant speed (4%, 1%, 1%).
- LV going straight, constant speed and FV decelerating (4%, 1%, 1%).
- LV merging and FV going straight, constant speed (4%, 1%, 0%).
- LV starting in traffic lane and FV starting in traffic lane (4%, 0%, 0%).
- LV stopped in traffic lane and FV stopped in traffic lane (4%, 0%, 0%).
- LV stopped in traffic lane and FV unknown (4%, 0%, 0%).

Note that all of the crashes are represented in the above percentages, but the total crashes add up to only 99 percent due to rounding.

DRIVER PHYSICAL/MENTAL IMPAIRMENT

Figure 45 shows that crashes are about equally likely to be coded as *no apparent impairment* and *distraction* (close to 40% each), while near-crashes have about 30 percent more events coded as *no apparent impairment* than as *distraction.* Over three times as many incidents were coded as *no apparent impairment* than as *distraction.* When a conflict is coded as impaired due to distraction, it is more likely to result in a crash than when it is coded as no apparent impairment. Drowsy/fatigued/asleep were fairly even for crashes, near-crashes, and incidents, at between 7 to 10 percent each. Tables A24 and A25 present the number and percentage of crashes, near-crashes, and incidents for which distraction was coded as a contributing factor. It should be noted that the *no apparent impairment* category could include cases in which there was a mental distraction such as daydreaming that could not be determined by the data reductionists.

Campbell, Smith, and Najm (2003) analyzed CDS and GES databases with regard to rear-end crashes. For CDS, inattention was the leading contributing factor, resulting in 39 percent of the crashes. For GES, inattention was the leading contributing factor, accounting for 65 percent of the crashes. If inattention is considered to be the same as distraction, the Campbell et al. (2003) CDS results are in close agreement with the 100-Car Study results in which 44 percent of the rear-end crashes were coded as driver impairment due to distraction. Campbell et al. (2003) also found that the driver was under the influence of alcohol in 7 percent of the cases and drugs in 1 percent of the cases, as compared to 4 percent for drugs and alcohol combined in the 100-Car Study. Keep in mind that the drivers knew that their actions were being videotaped, which may have resulted in a lower number of drug- and alcohol-related events than would occur without the presence of cameras.

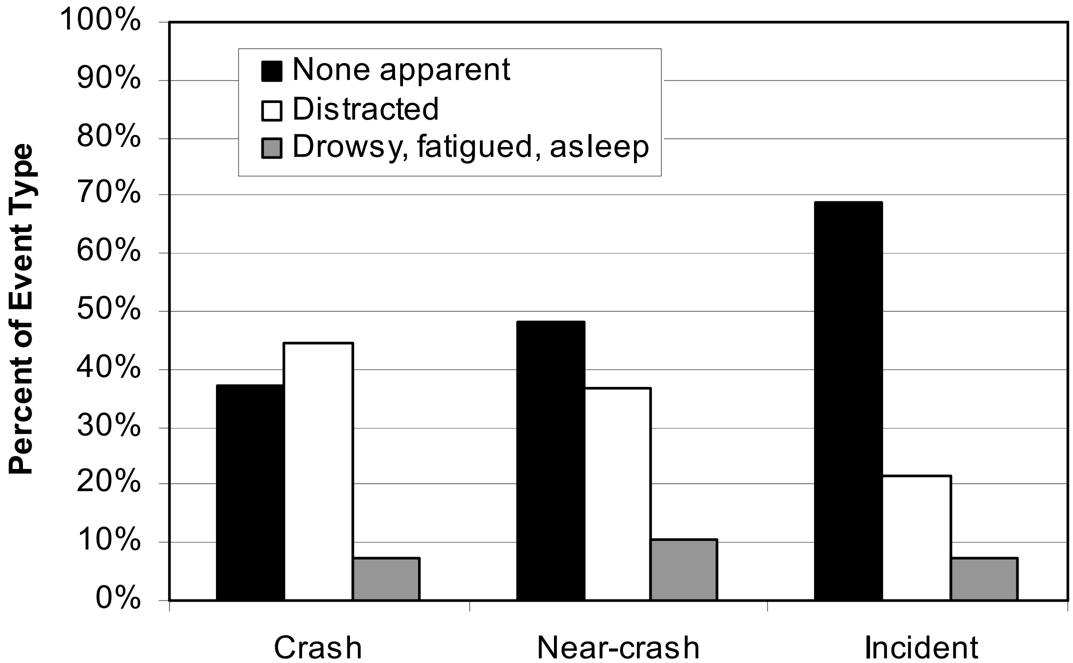

Figure 45. Percentage of *Conflict With LV* and *Conflict With FV* Events by Driver Impairment.

The next analysis considered whether the driver was considered to be competent to perform the driving maneuvers noted, given the driver's state of impairment. The categories of competency used by the data reductionists were:

- Competent.
- Driver capabilities (incompetent on what maneuvers are safe and appropriate).
- Driving techniques (incompetent to safely perform driving maneuver).
- Vehicle kinematics (incompetent handling the vehicle).
- Violation of traffic laws.

The most common categories of competency were *competent* and *driving technique* (Tables A26 and A27). There were very few cases of *violation of traffic laws*, *driving capabilities*, and *vehicle kinematics*. Figure 46 illustrates the percentage of events coded as other than competent for no apparent impairment, impairment due to distraction, and drowsy/fatigued/asleep. Drivers in crashes coded as being due to distraction were rated as competent in over 90 percent of cases, while drivers in crashes coded as being due to fatigue were rated as competent only 50 percent of the time. Drivers in crashes for which no impairment was noted were rated as competent 70 percent of the time. Near-crashes and incidents followed a similar pattern, although drivers were more likely to be rated as incompetent as event severity decreased.

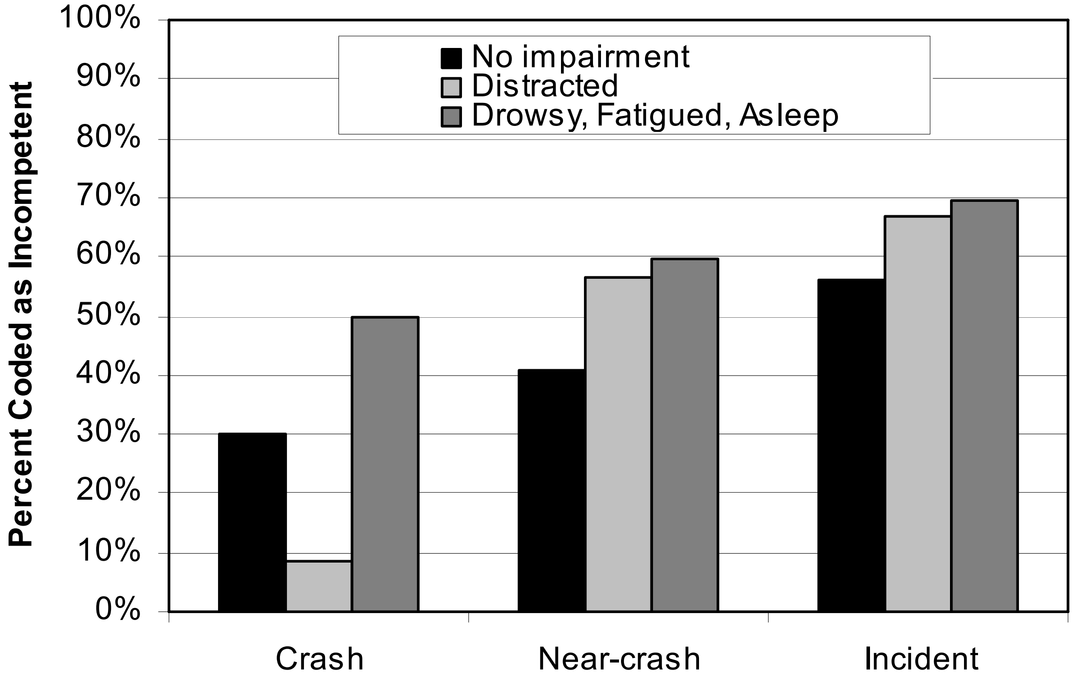

Figure 46. Percentage of *Conflict With LV* and *Conflict With FV* Events Coded as Other Than Competent by Driver Impairment.

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BASELINE BRAKING EVENTS ANALYSIS

PURPOSE

To obtain greater understanding of real-world driver braking behavior and vehicle conditions at time of braking.

METHOD

For this analysis, approximately 20 percent of the 100-Car database was data-mined to obtain baseline braking events. The Peeping Tom software program developed by VTTI was set up to data mine for braking events meeting certain criteria. Array 4 of the 100-Car database was used for the data mining. This array contains approximately 25 percent of the 100-Car data. The initial run through stopped when 80 percent of the array had been run through, resulting in approximately 500,000 braking events (as defined below) and representing about 20 percent of the 100-Car data. This sample of braking events was randomly assembled from the 100-Car database and therefore included instances of normal driving as well as critical events including incidents, near-crashes, and crashes.

An initial filter was then applied to eliminate those events in which the starting speed was 0 mph (the brakes were applied when the driver was already stopped). This reduced the number of events to about 480,000. Additional filters were then used to eliminate cases with out-of-bounds data points, missing data points, and data points in which there was no following vehicle. When this process was complete, there were approximately 189,000 baseline braking events remaining. The entire effort was accomplished with data mining (via the Peeping Tom software) and data filtering and cleaning (using SAS). No data reduction was performed (i.e., there was no video analysis or data reductionist time).

Assumptions

- Braking data from the 100-Car vehicles was used (braking parameters were not derived for either lead or following vehicles). Going through one array to obtain the braking events should provide a representative sample (we would not expect a person's braking behavior to change much over time). An attempt was made to get at least 1,000 braking events for each vehicle. However, by the time the data-mining and filtering process was complete, not every vehicle was represented, not every vehicle had an equal number of events, and it was unknown which driver was in that vehicle at the time the braking event occurred.
- The g level was measured with an accelerometer. Hills were not taken into account in calculating the g level. There was no measure of brake force in the data, only an indication of brakes applied or not and the resulting deceleration. Because the hills in the northern Virginia area are usually quite mild, the correlation between brake force and resultant deceleration should be quite high.
- The data are primarily presented on a per event basis (percent occurrence per braking event). The results are also presented on a per hour basis and a per mile basis.
- All analyses were conducted in SAS (with 189,000 braking events, the dataset was too large to manipulate in Excel).

Braking event definitions

- A braking event was defined as any time the brakes are applied (brake light on indicated in data stream) for ≥ 3 s. In addition, any time the brakes were applied again within 2 s of the initial event, the braking events were counted as one event. Braking events with a starting speed of 0 mph were removed from the dataset.
  - Start of braking event was defined as first sync number where brake lamps came on.
  - End of braking event was the last sync number where brakes were applied.
- For certain variables, the data were searched for 10 s beyond the start of the braking event to determine the final disposition (whether the vehicle sped up, slowed down, stopped, or remained at the same speed as a result of the braking event).

Variables obtained from data stream for each braking event

- Start of braking event.
- End of braking event.
- Peak deceleration obtained during event (exact value that was later placed in bins). Only events with a peak deceleration from 0 to -6 *g* were included in the final dataset.
- Vehicle speed at start of braking event (only events with values from 0 to 105 mph were included).
- Vehicle speed at end of braking event (only events with values from 0 to 105 mph were included).
- Minimum speed over time span from initial brake application until end of braking epoch (only events with values from 0 to 105 mph were included).
- Timing of minimum speed (to obtain time to full stop).
- Range for following vehicle at start of braking event and end of braking event (only events for which there was a following vehicle with a range from 0 to 600 ft at both the start and end of the event were included in the final dataset).

Variables derived from above variables for each braking event

- Duration of braking event (start minus stop).
- Speed differential over braking event (start speed minus minimum speed).
- Initial speed in bins:
  - ≤ 18.6 mph
  - 18.7 to 31 mph
  - > 31 mph
- Minimum speed in bins (same as above).
- Maximum speed in bins (same as above).
- Peak deceleration in bins:
  - ≤ .1 *g*
  - .11 to .3 *g*
  - .31 to .5 *g*
  - .51 to .7 *g*
  - > .7 *g*
- Range for following vehicle in bins (at start and end of event):
  - ≤ 25 ft
  - 26 to 50 ft

    - 51 to 100 ft
    - 101 to 150 ft
    - > 150 ft
- Vehicle disposition following braking:
    - Stopped (if minimum speed is less than 5 mph during braking epoch)
    - Slowed (if maximum speed is less than initial speed)
    - Accelerated (if maximum speed is greater than initial speed)
    - Steady speed (if maximum speed is within ±3 mph of initial speed)
- Time to stop (s)

QUESTIONS ANSWERED BY THE BASELINE BRAKING DATASET

1. How frequently (per braking maneuver) would a hypothetical, high-deceleration signal activate under normal driving? This question was answered by assessing the number of baseline braking events within the following peak *g* level bins (taken from Mercedes Benz and other proposed signal activation criteria):

- **≤ .1 *g***
- **.11 to .3 *g***
- **.31 to .5 *g***
- **.51 to .7 *g***
- **> .7 *g***

As can be seen in Figures 47 and 48, there were very few events with peak deceleration above 0.7*g* (only about 0.05 percent of events [93 of 189,067] were at this level or above). This compares to the Mercedes-Benz report of 23 peak deceleration >0.7*g* occurrences per 100,000 braking events (0.023 percent). This indicates that the Mercedes-Benz activation criteria underestimate the frequency with which the signal would be activated; nevertheless, the frequency is still quite small. The great majority of baseline events (68%) were in the 0.11 to 0.30*g* range. The rear lighting work performed over the past several years at VTTI suggests an activation criterion of >0.35g for an enhanced rear-lighting system; 7 percent of events met this criterion. Table 31 provides the descriptive statistics and percentile ranks for the peak deceleration parameter. Near-crash and incident comparison values are also included. As can be seen, both incidents and near-crashes exhibit much higher peak deceleration values than do these baseline braking events. For example, the median peak deceleration is 0.19*g* for baseline braking, 0.52*g* for incidents, and 0.74*g* for near-crashes.

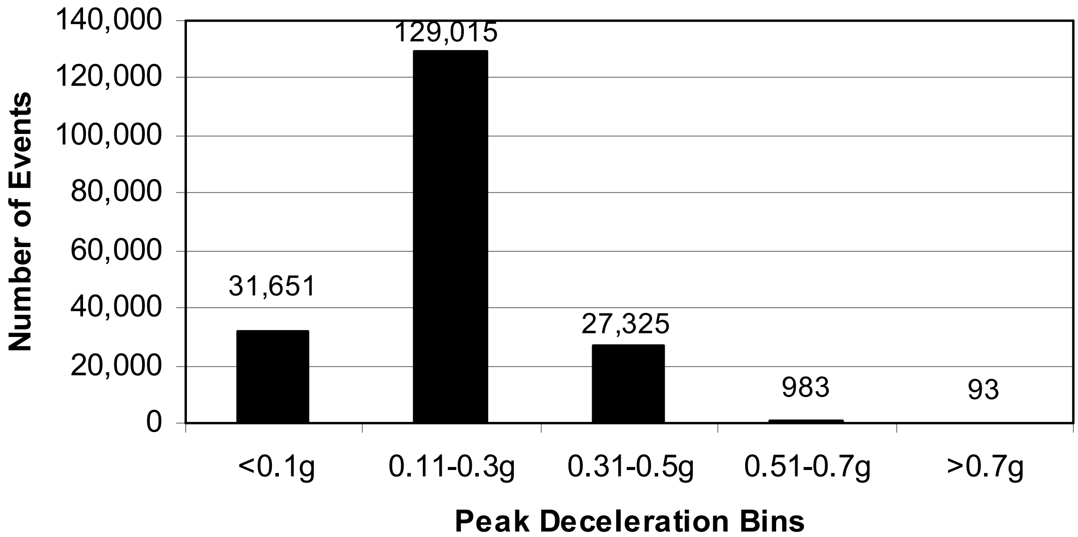


Figure 47. Number of baseline braking events for various deceleration levels.

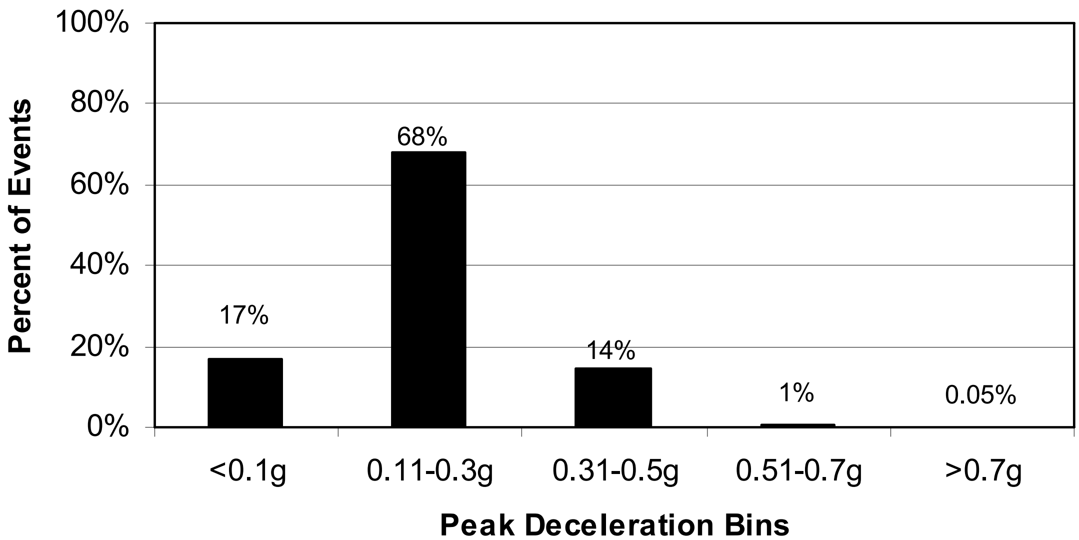


Figure 48. Percent of baseline braking events for various deceleration levels.

Table 31. Peak deceleration descriptive statistics and percentile ranks for the baseline braking events along with selected comparison values for near-crashes and incidents.

Parameter	Baseline Peak Decel (g)	Incident Peak Decel (g)	Near-crash Peak Decel (g)
N	189,067	2,694	159
Minimum	0.0001		
Maximum	5.671		
Mean	0.197		
Std Dev	0.102		
1st percentile	0.010		
5th percentile	0.046		
10th percentile	0.074	0.400	0.450
15th percentile	0.094		
20th percentile	0.110		
25th percentile	0.125	0.440	0.600
30th percentile	0.138		
35th percentile	0.152		
40th percentile	0.165		
45th percentile	0.177		
50th percentile	0.190	0.520	0.740
55th percentile	0.203		
60th percentile	0.216		
65th percentile	0.230		
70th percentile	0.245		
75th percentile	0.261	0.590	0.830
80th percentile	0.279		
85th percentile	0.300		
90th percentile	0.328	0.680	0.940
95th percentile	0.371		
99th percentile	0.467		

Figure 49 shows peak deceleration distributions for crash/near-crash events along with baseline events. As can be seen, peak decelerations of more than 0.4*g* almost never occurred for baseline events. For crashes and near-crashes, peak decelerations of less than 0.4*g* were rare. There is little overlap between the crash/near-crashes and baseline events. Based on Figure 49, a braking event with more than 0.4*g* is much more likely to be indicative of a crash or near-crash than of normal braking. This insight is even more powerful given that many of the higher deceleration level baseline events might truly be classified as crashes, near-crashes, or incidents (but were pulled from the data stream without the benefit of video data reduction).

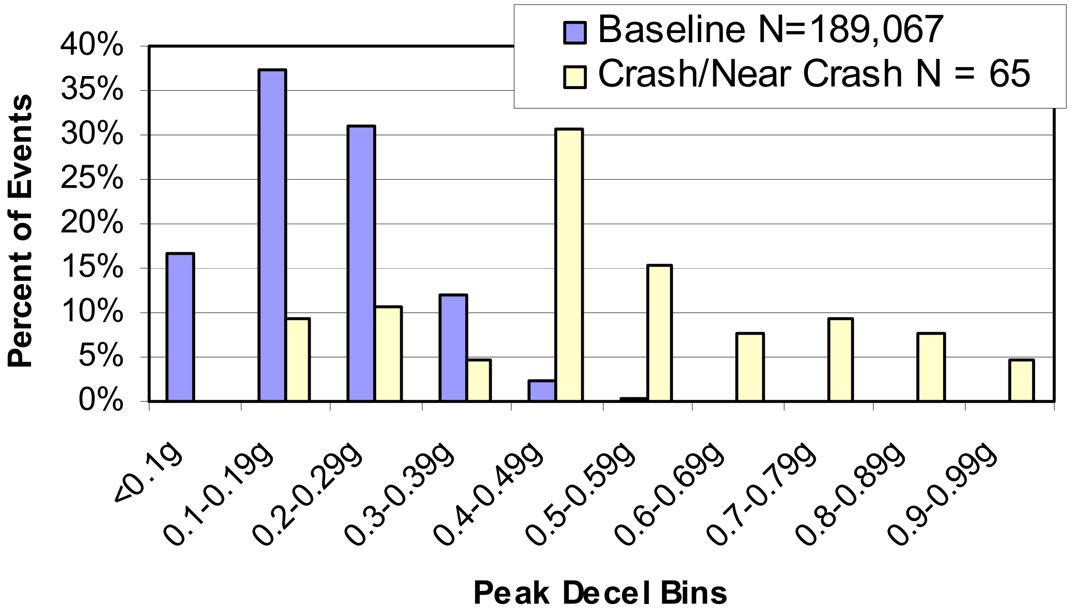


Figure 49. Peak deceleration distributions for baseline events and crashes/near-crashes.

Further insight was gained by decision matrices for potential deceleration criteria (0.4*g* and 0.55*g*) as presented in Tables 32 and 33. The tables are constructed according to event type. For example, given a baseline event, what is the probability of signal activation for a given criterion? These tables show the drastic changes that occur in false alarms and misses as the criterion level changes. For example, the miss rate exhibits a large increase when the criterion goes from 0.4*g* to 0.55*g* (going from 25% for 0.4*g* to 66% for 0.55*g*). The 0.4*g* criterion exhibits ten times as many false alarms (3%) as the 0.55*g* criterion (0.3%). Overall, these findings argue strongly for a criterion in the 0.35*g* to 0.4*g* range.

Table 32. Decision matrix for 0.4*g* criterion: Percent of event type (based on 189,067 baseline braking events and 65 rear-end crash/near-crash events.

0.4*g* Criterion		**Event Classification**	
		Baseline	Crash/Near-crash/
Signal Status	Active	3.0% False Alarms	75.0% Correct Activations
	Inactive	97.0% Correct Rejections	25.0% Misses

Table 33. Decision matrix for 0.55*g* criterion: Percent of event type (based on 189,067 baseline braking events and 65 rear-end crash/near-crash events.

0.55*g* Criterion		**Event Classification**	
		Baseline	Crash/Near-crash
Signal Status	Active	1.2% False Alarms	34.0% Correct Activations
	Inactive	98.8% Correct Rejections	66.0% Misses

Another way of examining the data are to look at exposure data: how often do decelerations of various levels occur on a per-1,000-mile or per-hour basis? There were approximately 47,000 driving hours in the 100-Car database. Since this analysis captured approximately 20 percent of the entire database, there were approximately 9,400 h for this analysis. Figure 50 shows that the most common deceleration category (0.11 to 0.3*g*) occurred about 14 times per hour of driving, while the highest category occurred only once per 100 h of driving. Events with a peak deceleration above 0.35*g* occurred 1.4 times per hour. The same data are also shown in terms of events per 1,000 mi of driving in Figure 51 (based on an average driving speed of 29 mph for the entire dataset). Events in the 0.11 to 0.3*g* range occurred almost once every 2 miles (473 times per 1,000 mi of driving), while those above 0.7*g* occurred about once per 3,000 mi. Events with a peak deceleration >0.35 *g* occurred 49 times per 1,000 mi of driving. These metrics are summarized in Table 34.

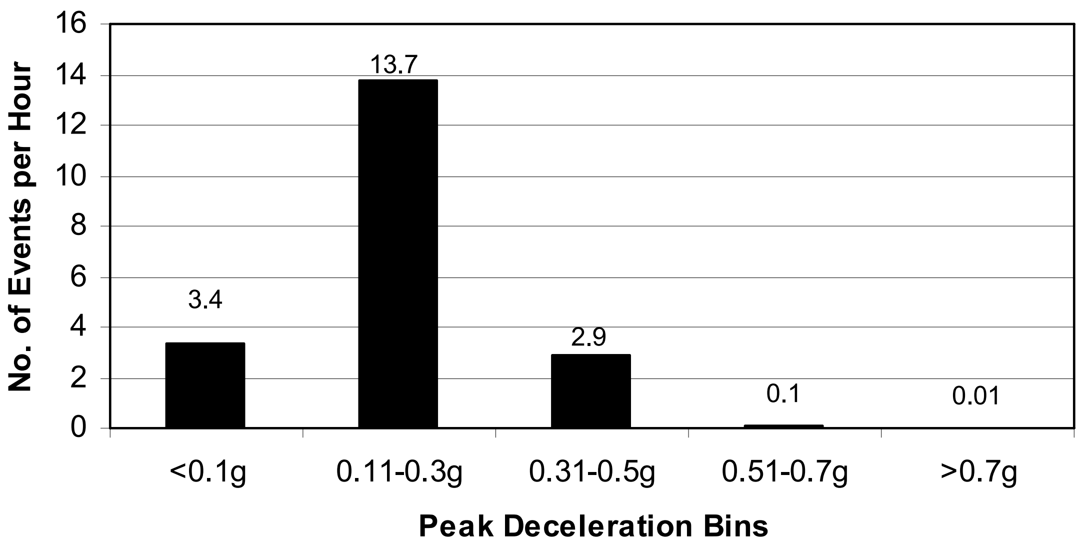


Figure 50. Number of baseline braking events per hour of driving.

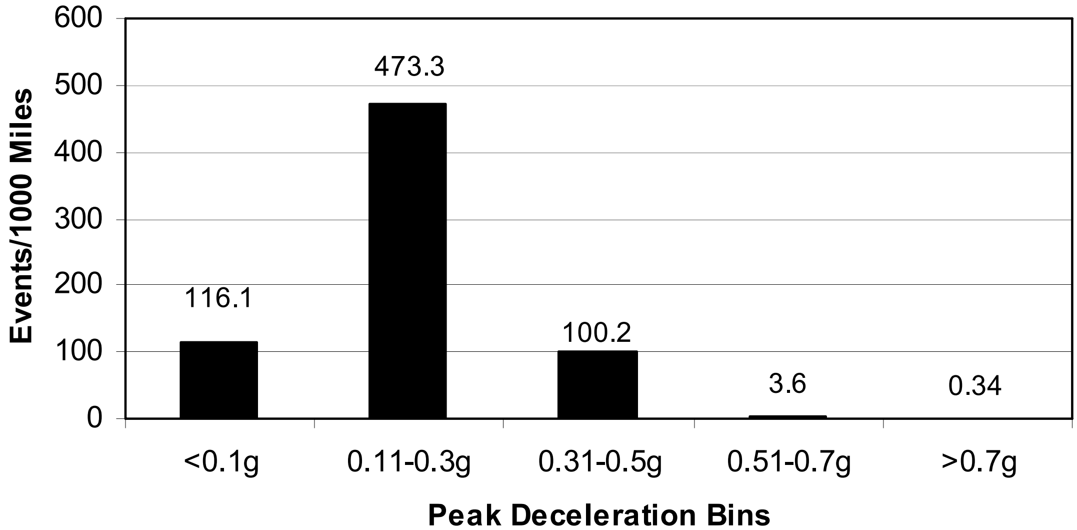


Figure 51. Number of baseline braking events per 1,000 miles of driving.

Table 34. Rates of activation for various hard-braking criteria.

Criterion	Percentage of Braking Events	Criterion Occurrence : All Braking Events	Rate per Hour	Rate per 1,000 miles
>0.30*g*	15%	1 : 7	3	104
>0.35*g*	7%	1 : 14	1.4	49
>0.40*g*	3%	1 : 33	0.6	21
>0.45*g*	1.3%	1 : 77	0.3	9
>0.50*g*	0.6%	1 : 176	0.1	4
>0.70*g*	0.05%	1 : 2,000	0.01	0.3

2. **To what extent do the *g* levels in the above bins occur at different velocities (values below derive from metric proposals for activation of different deceleration signals). What is the distribution of the above *g* level bins within each of the velocity ranges below?**
   - **≤ 18.6 mph**
   - **18.7 to 31 mph**
   - **> 31 mph**

A first examination of the starting velocity showed that the baseline braking events were evenly distributed across the three categories, as shown in Figures 52 and 53. The descriptive statistics and percentiles for starting velocity are shown in Table 35.

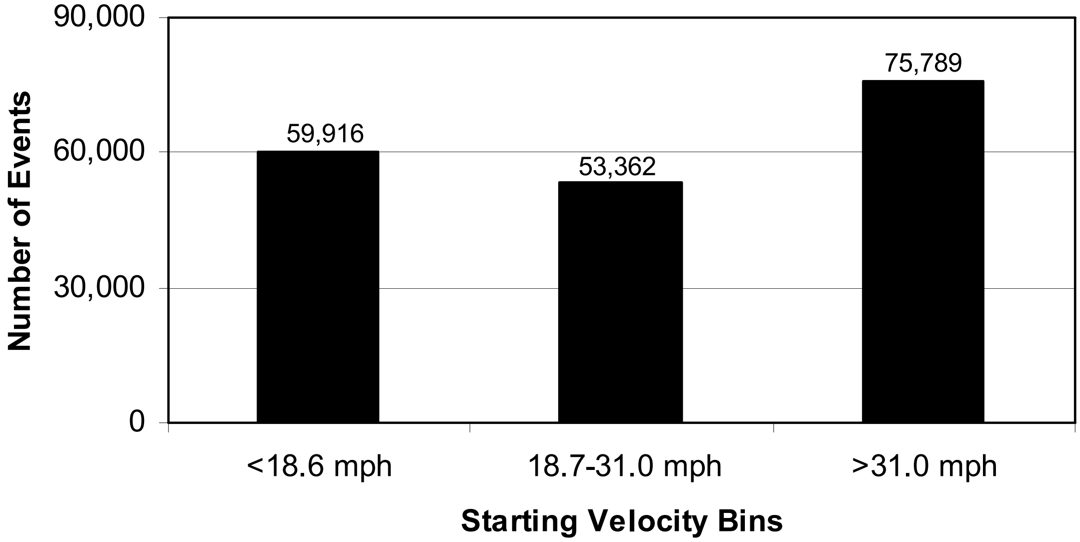


Figure 52. Number of baseline braking events for various starting velocities.

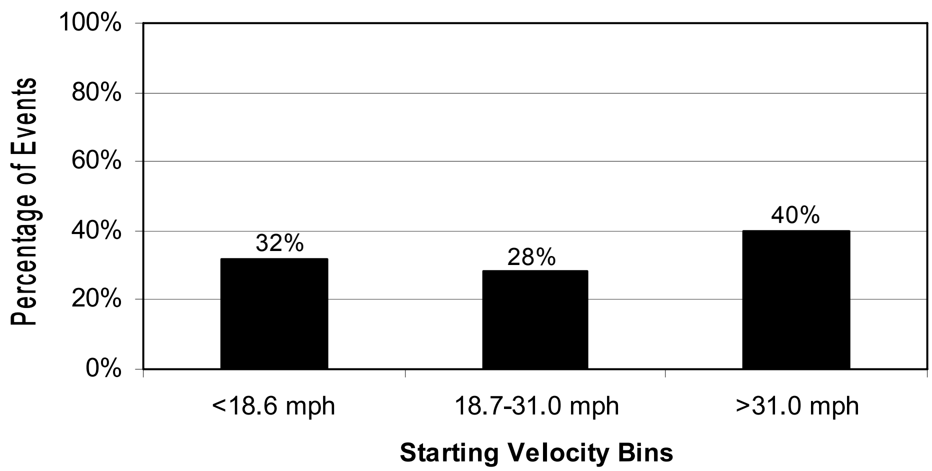
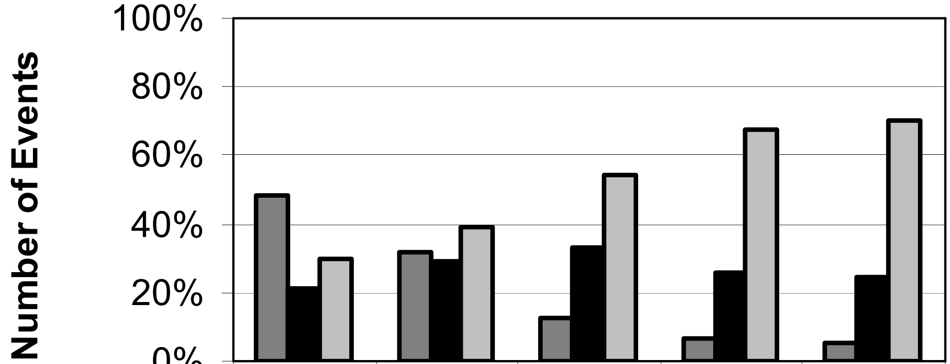


Figure 53. Percentage of baseline braking events for various starting velocities.

Table 35. Starting velocity (mph) descriptive statistics and percentile ranks for the baseline braking events.

Parameter	Value
N	189,067
Minimum	0.6
Maximum	100.7
Mean	27.47
Std Dev	15.49
1st percentile	2.5
5th percentile	5.0
10th percentile	7.5
15th percentile	9.9
20th percentile	12.4
25th percentile	14.9
30th percentile	17.4
35th percentile	19.9
40th percentile	22.4
45th percentile	24.2
50th percentile	26.7
55th percentile	28.6
60th percentile	31.1
65th percentile	32.9
70th percentile	35.4
75th percentile	37.3
80th percentile	40.4
85th percentile	43.5
90th percentile	48.5
95th percentile	55.9
99th percentile	67.1

For the starting velocity by peak deceleration analysis, each peak deceleration category was considered separately to determine whether peak deceleration was dependent on starting velocity. Each deceleration bin in Figure 54 is thus a distribution for that category, with starting velocity percentages summing to 100. There does appear to be a relationship between starting speed and peak velocity. For example, almost half of the very low deceleration category ($<0.1g$) occurred at the lowest starting velocity, while 70 percent of the highest deceleration category events ($>0.7g$) occurred at the highest starting velocity. A regression analysis showed that this trend was significant ($F_{1,\ 189{,}063} = 9{,}234$, $p < 0.0001$); however, the low *R square* value of 0.047 indicates that the significance was likely driven by the large sample size. Figure 55 shows a regression plot of the data (with 2 outlier data points removed). The overall conclusion is that there is a slight trend towards higher peak deceleration values for higher starting velocities; however, very high peak decelerations are rare.



	<0.1g	0.11-0.3g	0.31-0.5g	0.51-0.7g	>0.7g
<18.6 mph	49%	32%	13%	7%	5%
18.7-31.0 mph	21%	29%	33%	26%	25%
>31.0 mph	30%	39%	54%	67%	70%

Peak Deceleration Bins

Figure 54. Distributions of various starting velocity categories for peak deceleration bins.

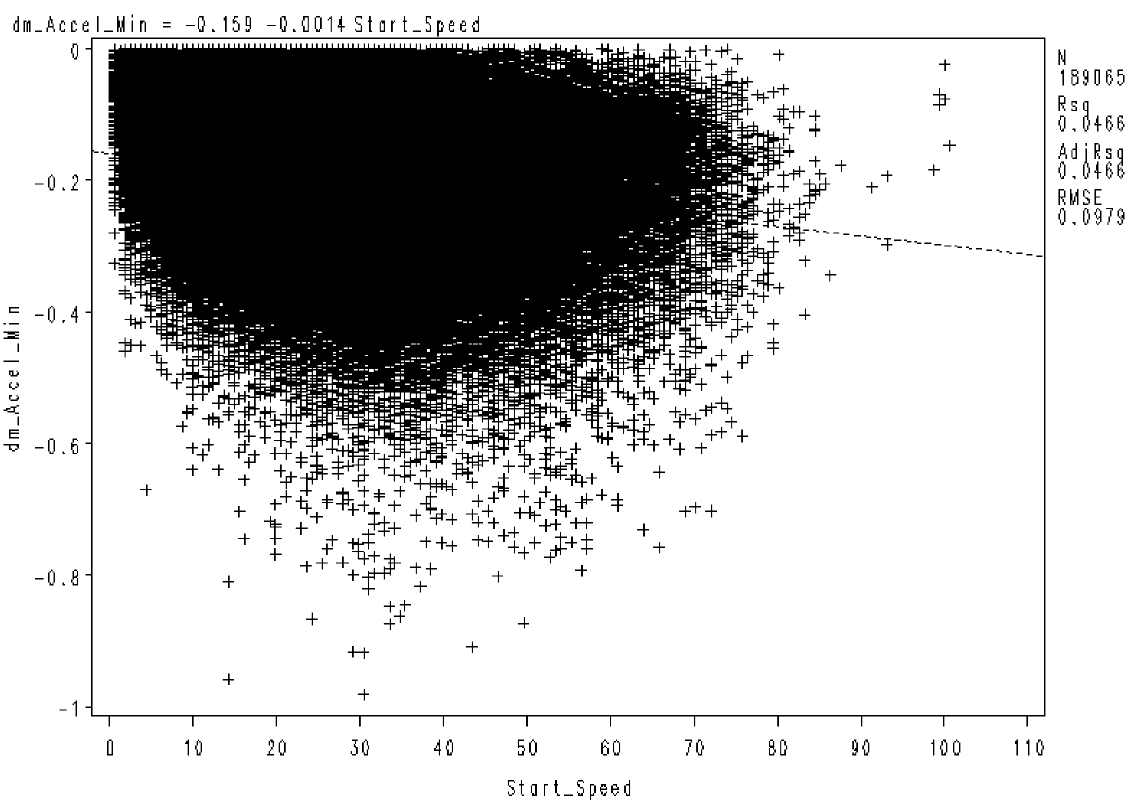


Figure 55. Linear regression plot of baseline braking events, with peak deceleration plotted against starting velocity. The dashed line represents the line of best fit.

3. To what extent would high deceleration-based signals activate when following vehicles are close versus not close (time headway, defined as range/range rate)? How close were vehicles at the different deceleration levels? The rear radar range data were placed in the following time headway bins:

- **≤ 1.0 s**
- **1.1 to 1.5 s**
- **1.6 to 2.0 s**
- **2.1 to 3.0 s**
- **> 3.0 s**

Figure 56 provides the distribution of baseline braking events for various FV starting headways, while Figure 57 shows that only about 9 percent of these events began with a following vehicle at ≤1.0 s. The largest headway category was >3.0 s, with over half of events falling into this category. When the peak deceleration bins were crossed with the FV range categories as shown in Figure 58, the only noticeable trend is a greater proportion of the higher deceleration categories occurred at lower headways, which seems counterintuitive. In 10 percent of the hard braking cases (>0.7*g*), there was a following vehicle with less than 1 s of headway (in other words, the LV was being tailgated when the hard braking began).

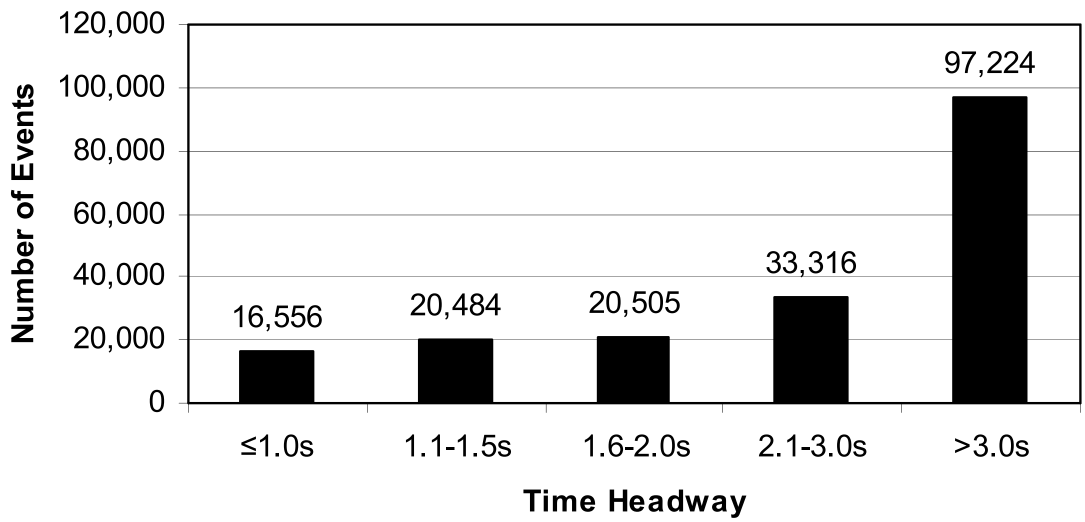


Figure 56 . Number of baseline braking events for various FV starting headways.

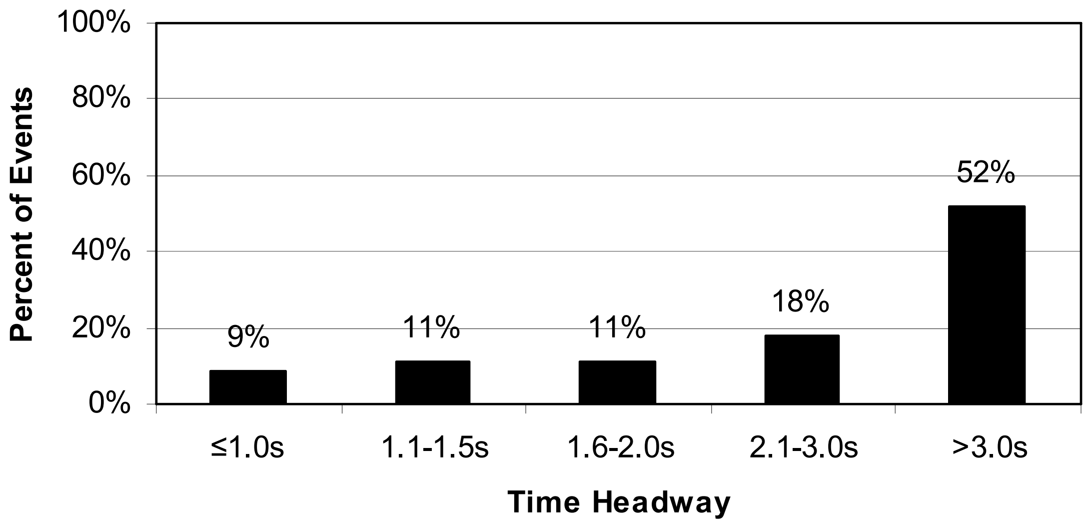
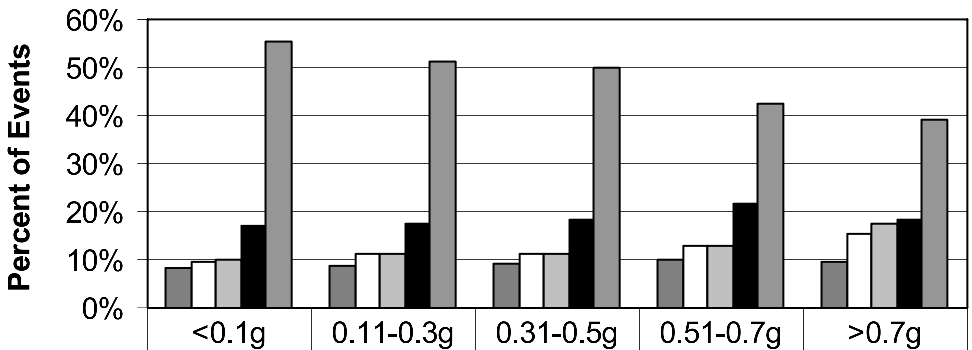


Figure 57. Percent of baseline braking events for various FV starting headways.



	<0.1g	0.11-0.3g	0.31-0.5g	0.51-0.7g	>0.7g
≤1.0s	8%	9%	9%	10%	10%
1.1-1.5s	10%	11%	11%	13%	15%
1.6-2.0s	10%	11%	11%	13%	17%
2.1-3.0s	17%	18%	18%	21%	18%
>3.0s	55%	51%	50%	43%	39%

Time Headway

Figure 58. Distributions of various FV starting headway categories for peak deceleration bins.

A linear regression with a cutoff of 100 s of headway showed a slight, significant trend, as shown in Figure 59 ($F_{1, 187,910} = 2482.16$, $p < 0.0001$). However, the *R square* value was very low, at 0.01. A linear regression of just the high-deceleration events (with peak deceleration between -0.7*g* and -1.0*g*) was not significant ($F_{1, 89} = 0.13$, $p = 0.7233$, *R squared* = 0.0014).

As seen in Figure 60, this indicates that LV drivers did not modulate braking based on the FV headway.

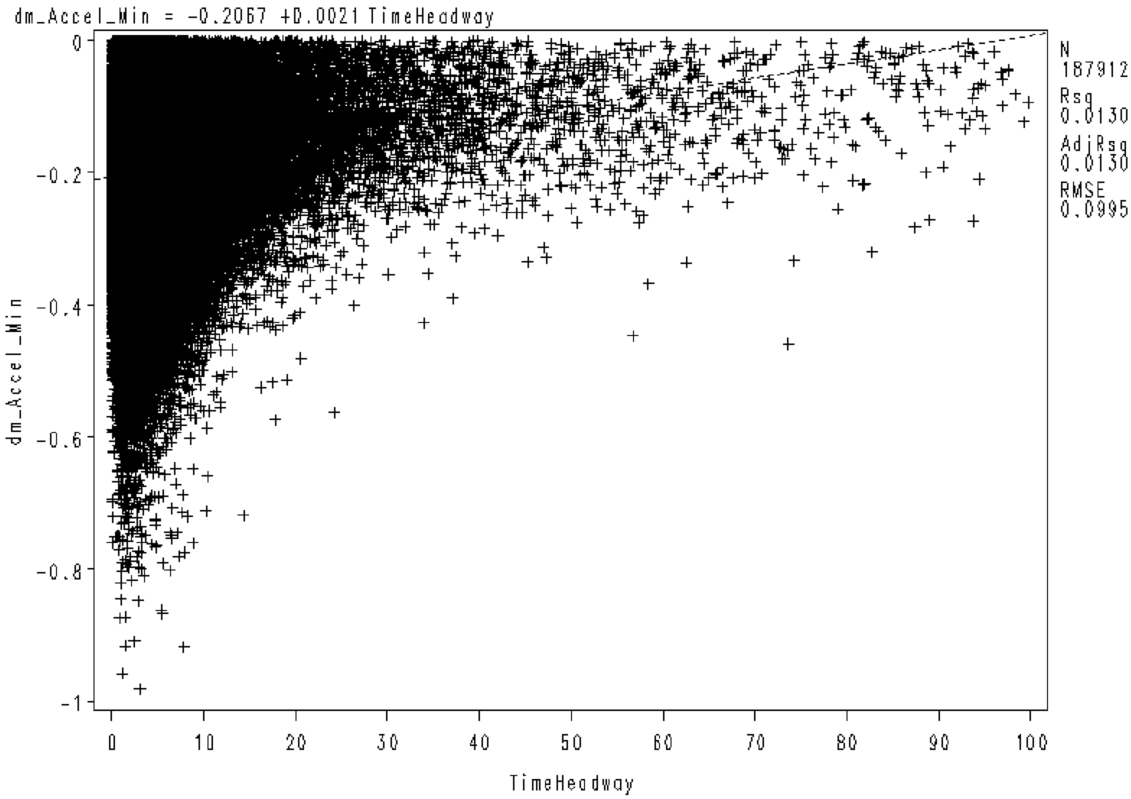


Figure 59. Linear regression plot of baseline braking events, with peak deceleration plotted against FV starting headway. The dashed line represents the line of best fit.

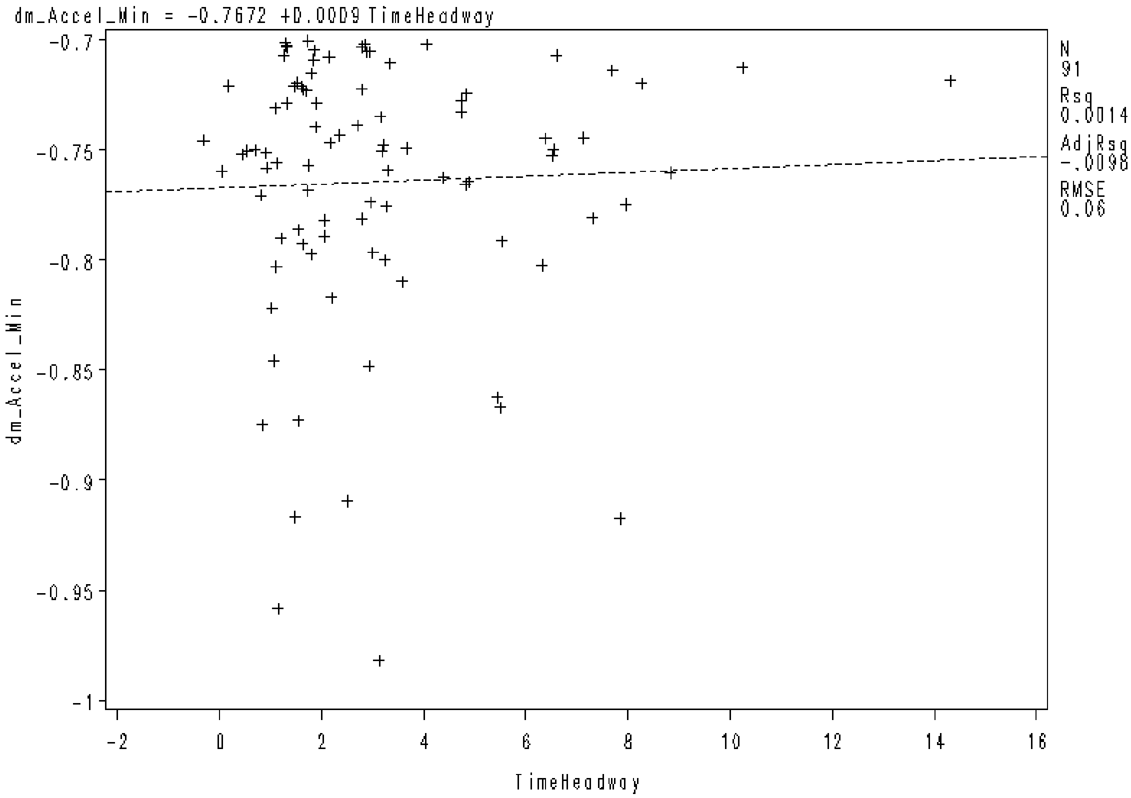


Figure 60. Linear regression plot of high deceleration baseline braking events, with peak deceleration plotted against FV starting headway. The dashed line represents the line of best fit.

The headway to the following vehicle at the end of the event was also captured. Figure 61 shows the FV ending headway, while Figure 62 compares the starting and ending headway distributions. The percent of vehicle in the shortest headway (≤1.0 s) increased noticeably from the start to the end of the event, while the number in the longest headway categories (>2.0 s) decreased slightly. The descriptive statistics and percentile values for the starting and ending following headways are presented in Table 36 along with a few comparison points for near-crashes and incidents. These data were filtered to ensure valid starting and ending values. As can be seen, braking events generally led to a narrowing of the headway between the lead and following vehicles. For example, the 50th percentile for starting headway was 3.1 s, while the 50th percentile for ending headway was 2.9 s, a 6-percent decrease in FV headway over the duration of the braking event. By comparison, the median headway for incidents was 1.5 s and for near-crashes, it was 1.4 s.

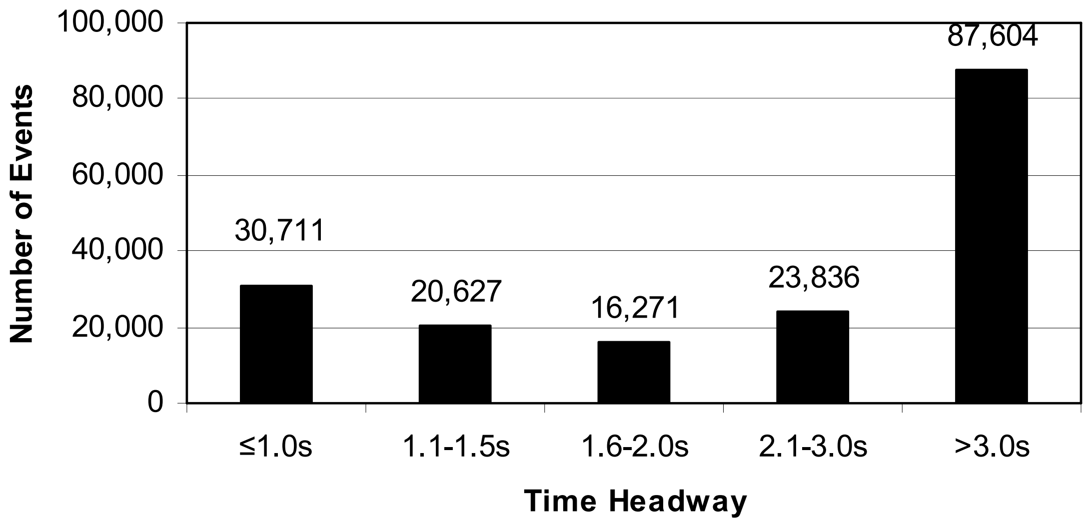


Figure 61. Number of baseline braking events for various FV ending headway.

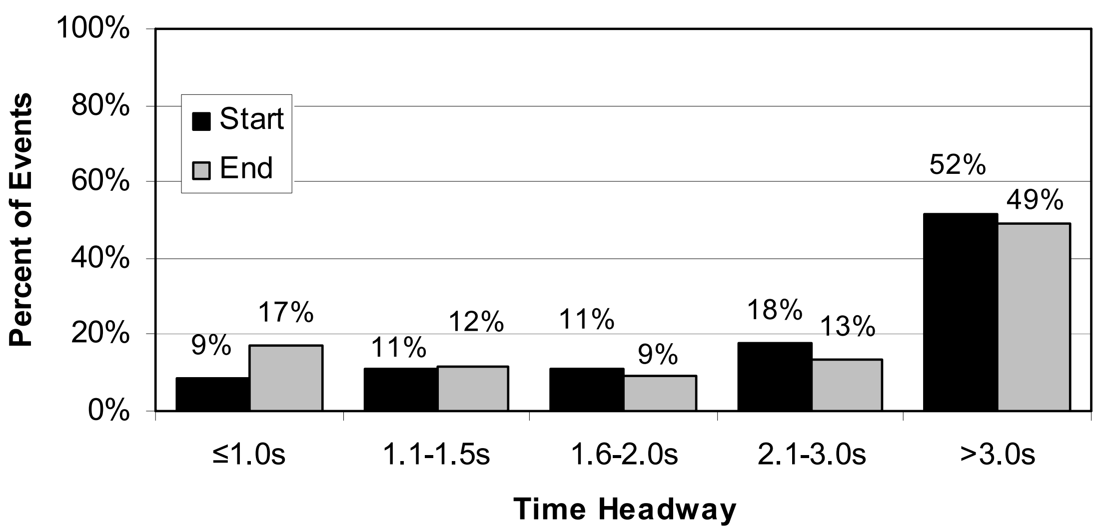


Figure 62. Percent of baseline braking events for various FV starting and ending headways.

Table 36. Following-vehicle headway descriptive statistics and percentile ranks for the baseline braking events, with comparison values for near-crashes and crashes.

Parameter	Starting Headway (s)	Ending Headway (s)	Incident Headway (s)	Near-Crash Headway (s)
N	188,085	179,049	769	47
Minimum	0.001	0.002		
Maximum	506.1	521.8		
Mean	4.52	5.95		
Std Dev	7.613	12.429		
1st percentile	0.18	0.19		
5th percentile	0.77	0.48		
10th percentile	1.06	0.71	0.67	0.58
15th percentile	1.30	0.91		
20th percentile	1.51	1.12		
25th percentile	1.74	1.33	0.98	0.81
30th percentile	1.97	1.57		
35th percentile	2.22	1.84		
40th percentile	2.50	2.14		
45th percentile	2.79	2.50		
50th percentile	3.11	2.90	1.53	1.38
55th percentile	3.45	3.37		
60th percentile	3.83	3.90		
65th percentile	4.23	4.52		
70th percentile	4.70	5.29		
75th percentile	5.24	6.25	2.69	2.46
80th percentile	5.90	7.53		
85th percentile	6.79	9.39		
90th percentile	8.19	12.49	4.37	3.35
95th percentile	11.33	19.37		
99th percentile	26.88	50.72		

4. **What was the final disposition of the high deceleration (>0.7*g*) braking events? How many ended in a stop (defined as less than 5 mph velocity) versus a slowdown, acceleration, or transition to steady speed?**

Figure 63 shows the final disposition (10 s after the start of the braking event) for the 93 cases of deceleration >0.7*g*. At this level of deceleration, the event almost always resulted in a stop (54 percent) or slowing (43%), as opposed to a speed up or reversion to the same speed. Thus, in over half of the high-*g* cases, a stop resulted within 10 s after the braking began. It is likely given the process used in creating the 100-Car event dataset that all 93 cases were classified as crashes, near-crashes, or incidents, and thus no comparison between events and non-events was attempted.

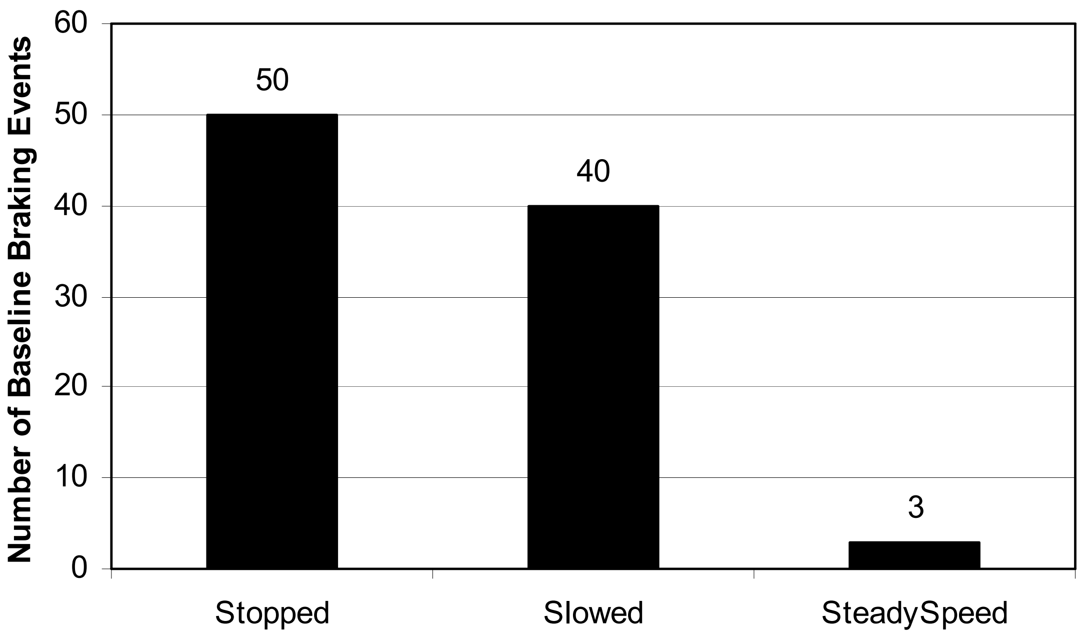
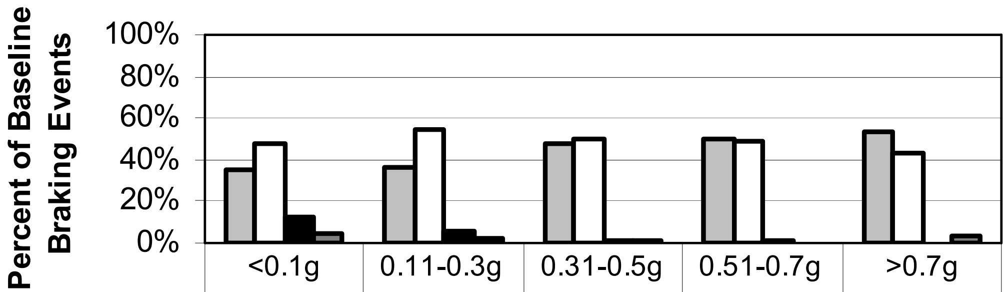


Figure 63. Disposition of baseline braking events with deceleration >0.7*g*.

For comparison purposes, Figure 64 shows the final disposition for all categories of deceleration. It can be seen that as braking level increased, events were increasingly likely to end in a stop and less likely to end in slowing, acceleration, or reversion to the same speed. With a >0.35*g* activation criterion, 49 percent of events resulted in a stop, 49 percent in a slowing, and 1 percent each in acceleration or reversion to steady speed (quite similar to the 0.51 to 0.70*g* distribution in Figure 64).



	<0.1g	0.11-0.3g	0.31-0.5g	0.51-0.7g	>0.7g
Stopped	35%	37%	47%	50%	54%
Slowed	48%	55%	50%	49%	43%
Accelerated	12%	6%	1%	1%	0%
SteadySpeed	5%	3%	1%	0%	3%

Peak Deceleration Bins

Figure 64. Distributions of various disposition categories for peak deceleration bins.

5. What is the distribution of braking duration (for all events) and time to full stop (for those events ending in a stop)?

Table 37 shows the braking duration descriptive statistics and percentiles for those events in which the braking duration was 1 min or less. There were some events (in stop-and-go traffic) that lasted longer than 1 min, but these were not considered to be representative for developing distributions of braking duration. As seen in Table 37, the braking length duration is skewed towards the shorter durations tailing off to the longer durations, with a median (50^{th} percentile) of 6.2 s and a mean of 9.3 s. Selected comparison values for near-crashes and incidents are also provided. As can be seen, braking durations were much shorter for near-crashes and incidents (median values of 6.2 s for baseline braking, 4.0 s for incidents, and 3.3 s for near-crashes). As shown previously, drivers braked much harder for near-crashes and incidents, and thus probably did not have to brake for as long.

Table 38 presents the time to full stop data for the 68,000 events resulting in a stop (these events were also constrained to those braking events lasting 1 min or less). In this case the mean time to a full stop was 8.1 s and the median was 6.7 s.

Table 37. Braking-event duration descriptive statistics and percentile ranks for the baseline braking events with selected comparison values for near-crashes and incidents.

Parameter	Baseline Braking Duration (s)	Incident Braking Duration (s)	Near-Crash Braking Duration (s)
N	180,426	2,128	133
Minimum	3		
Maximum	59.9		
Mean	9.3		
Std Dev	8.511		
1st percentile	3.0		
5th percentile	3.2		
10th percentile	3.4	1.4	1.3
15th percentile	3.6		
20th percentile	3.9		
25th percentile	4.2	2.5	2.0
30th percentile	4.5		
35th percentile	4.9		
40th percentile	5.2		
45th percentile	5.7		
50th percentile	6.2	4.0	3.3
55th percentile	6.8		
60th percentile	7.5		
65th percentile	8.3		
70th percentile	9.3		
75th percentile	10.6	6.3	5.3
80th percentile	12.3		
85th percentile	14.7		
90th percentile	18.6	9.0	8.7
95th percentile	26.8		
99th percentile	47.2		

Table 38. Braking-event duration descriptive statistics and percentile ranks for the baseline braking events.

Parameter	Value (s)
N	67,818
Minimum	0
Maximum	58.5
Mean	8.1
Std Dev	5.458
1^{st} percentile	0.3
5^{th} percentile	2.3
10^{th} percentile	2.8
15^{th} percentile	3.2
20^{th} percentile	3.6
25^{th} percentile	3.9
30^{th} percentile	4.4
35^{th} percentile	4.9
40^{th} percentile	5.5
45^{th} percentile	6.1
50^{th} percentile	6.7
55^{th} percentile	7.4
60^{th} percentile	8.2
65^{th} percentile	9.1
70^{th} percentile	10.0
75^{th} percentile	11.1
80^{th} percentile	12.2
85^{th} percentile	13.6
90^{th} percentile	15.6
95^{th} percentile	18.6
99^{th} percentile	25.6

CONCLUSIONS FOR BASELINE BRAKING EVENT ANALYSIS

An additional analysis was performed to establish the parameters of baseline braking events. These were braking events lasting at least 3 s and captured using VTTI data-mining software. After data-mining approximately 20 percent of the 100-Car complete database, nearly 500,000 of these events were captured. The baseline braking events were then filtered to include only those meeting certain criteria relevant to the questions of interest. This filtering resulted in a final baseline braking event dataset containing just over 189,000 events. Some of the baseline braking events may also have been included in the 100-Car event database as a crash, near-crash, or incident.

One of the primary purposes of the baseline braking event analysis was to determine the potential impact of various hard-braking activation criteria. One proposed criteria is for a hard-braking signal that activates with peak deceleration >0.7*g*. In the baseline braking event database, this level occurred infrequently (0.05% of braking events, or once out of every 2,000 braking events, or once per 100 h of driving, or once per 3,000 mi). A European study found that such a signal would be activated even less frequently, at approximately once every 4,300 braking events. A second proposed criterion is for activation at peak deceleration >0.35*g*. This type of signal would occur much more frequently (approximately 7% of braking events, or once out of every 14 braking events, or 1.4 times per hour of driving, or 79 times per 1,000 mi of driving). Following are other potential activation criteria based on percentile rank:

- 0.1 percent of braking events had a peak deceleration of >0.63*g*,
- 0.5 percent of braking events had a peak deceleration of >0.51*g*,
- 1 percent of braking events had a peak deceleration of >0.47*g*, and
- 5 percent had a peak deceleration >0.37*g*.

Key findings from the baseline braking analysis include:

- One proposed activation criterion for hard braking is peak deceleration >0.7*g*. A hard-braking signal activated by this criterion would make up only 0.05 percent of braking events. This rate is approximately equal to:
  - Once out of every 2,000 braking events, or
  - Once per 100 h of driving, or
  - Once per 3,000 mi.
- Another proposed criterion for a hard braking signal is >0.35*g* peak deceleration. Events meeting this criterion made up approximately 7 percent of braking events. This rate is approximately equal to:
  - Once out of every 14 braking events, or
  - 1.4 times per hour of driving, or
  - 49 times per 1,000 mi of driving.
- The criterion which seems to have the least overlap between baseline events and conflict events (crashes and near-crashes) is >0.4*g* peak deceleration. Events meeting this criterion made up approximately 3 percent of baseline braking events (compared with 75% of crash/near-crash events). This rate is approximately equal to:
  - Once out of every 33 braking events, or
  - 0.6 times per hour of driving, or
  - 21 times per 1,000 mi of driving.
- Peak deceleration varies according to event severity. For example, median peak deceleration was 0.19*g* for baseline driving, 0.52*g* for incidents, and 0.74*g* for near-crashes.
- There appears to be a relationship between speed at the start of the braking event and peak velocity. For example, almost half of the very low deceleration category (<0.1*g*) occurred at the lowest starting velocity, while 70 percent of the highest deceleration category events (>0.7*g*) occurred at the highest starting velocity.
- Median following vehicle time headway was shorter for near-crashes (1.38 s) and incidents (1.53 s) as compared to baseline braking (3.11 s).
- Drivers with a peak deceleration greater than 0.7*g* apparently decelerated without regard to FV headway.

- Braking events generally led to a shorter headway between the lead and following vehicles. For example, the 50th percentile for starting headway was 3.1 s, while the 50th percentile for ending distance was 2.9 s, a 6-percent decrease.
- As braking level increased, events were increasingly likely to end in a stop and less likely to end in slowing, acceleration, or reversion to the same speed. This final disposition was determined 10 s after the braking event began.
  - With a >0.7*g* activation criterion, 54 percent of events resulted in a stop, 43 percent in a slowing, and 3 percent in reversion to steady speed.
  - With a >0.35*g* activation criterion, 49 percent of events resulted in a stop, 49 percent in a slowing, and 1 percent each in acceleration or reversion to steady speed.
- Braking event duration can be characterized as follows:
  - Mean duration of 9.3 s.
  - Standard deviation of 8.5 s.
  - Median of 6.2 s (as compared to 4.0 s for incidents and 3.3 s for near-crashes).
  - 5th percentile of 3.2 s (only 5% of events lasted less than 3.2 s)
  - 95th percentile of 26.8 s (only 5% of events lasted more than 26.8 s)
- Time to full stop can be characterized as follows:
  - Mean duration of 8.1 s.
  - Standard deviation of 5.5 s.
  - Median of 6.7 s.
  - 5th percentile of 2.3 s (only 5% of events lasted less than 2.3 s)
  - 95th percentile of 18.6 s (only 5% of events lasted more than 18.6 s)

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APPENDIX A. QUESTION 9 SUPPORTING TABLES

Table A1. Distribution of *Conflict With LV* and *Conflict With FV* Events by Age and Severity.

Age Group	Severity			
	Crash	Near-Crash	Incident	Total
18-20	3	157	1,769	1,929
21-24	5	55	988	1,048
25-34	8	44	776	828
35-44	3	87	1,216	1,306
45-54	2	37	817	856
55+	3	32	400	435
Total	24	412	5,966	6,402

Table A2. Percentage of *Conflict With LV* and *Conflict With FV* Events by Age and Severity. Items in gray indicate overrepresentation as compared to presence in the population.

Age Group (Percentage)	Severity			
	Crash	Near-Crash	Incident	Total
18-20 (15%)	12.5%	38.1%	29.7%	30.1%
21-24 (20%)	20.8%	13.3%	16.6%	16.4%
25-34 (17%)	33.3%	10.7%	13.0%	12.9%
35-44 (18%)	12.5%	21.1%	20.4%	20.4%
45-54 (18%)	8.3%	9.0%	13.7%	13.4%
55+ (12%)	12.5%	7.8%	6.7%	6.8%
Total	100.0%	100.0%	100.0%	100.0%

Table A3. Distribution of *Conflict With LV* and *Conflict With FV* Events by Sex, Age, and Severity.

Sex	Severity				
	Age Group	Crash	Near-Crash	Incident	Total
Female	18-20	2	101	1,303	1,406
	21-24	3	32	569	604
	25-34	1	19	173	193
	35-44	0	32	267	299
	45-54	0	20	390	410
	55+	0	3	26	29
Male	18-20	1	56	466	523
	21-24	2	23	419	444
	25-34	7	25	603	635
	35-44	3	55	949	1,007
	45-54	2	17	427	446
	55+	3	29	374	406
Total		24	412	5,966	6,402

Table A4. Percentage of *Conflict With LV* and *Conflict With FV* Events by Sex, Age, and Severity. Items in gray indicate overrepresentation as compared to presence in the population.

Sex	Severity				
	Age Group (Percentage)	Crash	Near-Crash	Incident	Total
Female	18-20 (8.3%)	8.3%	24.5%	21.8%	22.0%
	21-24 (10.1%)	12.5%	7.8%	9.5%	9.4%
	25-34 (6.4%)	4.2%	4.6%	2.9%	3.0%
	35-44 (3.7%)	0.0%	7.8%	4.5%	4.7%
	45-54 (6.4%)	0.0%	4.9%	6.5%	6.4%
	55+ (4.6%)	0.0%	0.7%	0.4%	0.5%
Male	18-20 (6.4%)	4.2%	13.6%	7.8%	8.2%
	21-24 (9.2%)	8.3%	5.6%	7.0%	6.9%
	25-34 (11.0%)	29.2%	6.1%	10.1%	9.9%
	35-44 (14.7%)	12.5%	13.3%	15.9%	15.7%
	45-54 (11.9%)	8.3%	4.1%	7.2%	7.0%
	55+ (7.3%)	12.5%	7.0%	6.3%	6.3%
Total		100.0%	100.0%	100.0%	100.0%

Table A5. Distribution of *Conflict With LV* and *Conflict With FV* Events by Precipitating Event and Severity.

Precipitating Event	Severity			
	Crash	Near-Crash	Incident	Total
LV Decelerating	0	172	2,794	2,966
LV Stopped > 2 s	8	44	1,331	1,383
LV Stopped ≤ 2 s	7	85	1,089	1,181
LV Accelerating	0	1	12	13
LV Slower Constant Speed	0	6	131	137
SV Decelerating	4	22	153	179
SV Stopped > 2 s	4	0	48	52
SV Stopped ≤ 2 s	3	16	46	65
SV Slower Constant Speed	0	0	18	18
POV - backing	0	0	16	16
POV entering intersection - intended path unknown	0	0	3	3
POV entering intersection - left turn across path	0	2	6	8
POV entering intersection - straight across path	0	0	3	3
POV entering intersection - turning opposite direction	0	0	2	2
POV entering intersection - turning same direction	0	5	18	23
POV from another lane	0	0	1	1
POV from driveway - intended path unknown	0	0	2	2
POV from driveway - straight across path	0	0	1	1
POV from driveway - turning into same direction	0	2	3	5
POV from parallel/diagonal parking lane	0	1	9	10
POV lane change - left behind SV	0	0	2	2
POV lane change - left in front of SV	0	34	145	179
POV lane change - left other	1	0	8	9
POV lane change - right behind SV	0	0	5	5
POV lane change - right in front of SV	0	34	203	237
POV lane change - right other	0	1	10	11
Pedalcyclist or non-motorist in roadway	0	0	1	1
Pedestrian approaching roadway	0	1	0	1
Pedestrian in roadway	0	0	1	1
Same direction changing lanes	0	0	2	2
SV in intersection - passing through	0	0	7	7
SV in intersection - turning left	0	0	3	3
SV in intersection - turning right	0	1	3	4
SV lane change - left behind vehicle	0	2	37	39
SV lane change - left in front of vehicle	0	10	212	222
SV lane change - left other	0	0	11	11
SV lane change - right behind vehicle	0	3	45	48
SV lane change - right in front of vehicle	0	7	135	142
SV lane change - right other	0	0	11	11
SV over left lane line	0	1	4	5
SV over right lane line	0	0	8	8
Object in roadway	0	0	1	1
No analyzed data	0	0	6	6
No precipitating events	0	0	1	1
Total	27	450	6,547	7,024

Table A6. Distribution of *Conflict With LV* and *Conflict With FV* Events by Lane Change Event Categories and Severity.

Precipitating Event	Severity			
	Crash	Near-Crash	Incident	Total
Same direction changing lanes	0	0	2	2
POV lane change - left behind SV	0	0	2	2
POV lane change - left in front of SV	0	34	145	179
POV lane change - left other	1	0	8	9
POV lane change - right behind SV	0	0	5	5
POV lane change - right in front of SV	0	34	203	237
POV lane change - right other	0	1	10	11
SV lane change - left behind vehicle	0	2	37	39
SV lane change - left in front of vehicle	0	10	212	222
SV lane change - left other	0	0	11	11
SV lane change - right behind vehicle	0	3	45	48
SV lane change - right in front of vehicle	0	7	135	142
SV lane change - right other	0	0	11	11
Total	1	91	826	918

Table A7. Percentage of *Conflict With LV* and *Conflict With FV* Events by Lane Change Event Categories and Severity.

Precipitating Event	Severity			
	Crash	Near-Crash	Incident	Total
Same direction changing lanes	0.0%	0.0%	0.2%	0.2%
POV lane change - left behind SV	0.0%	0.0%	0.2%	0.2%
POV lane change - left in front of SV	0.0%	37.4%	17.6%	19.5%
POV lane change - left other	100.0%	0.0%	1.0%	1.0%
POV lane change - right behind SV	0.0%	0.0%	0.6%	0.5%
POV lane change - right in front of SV	0.0%	37.4%	24.6%	25.8%
POV lane change - right other	0.0%	1.1%	1.2%	1.2%
SV lane change - left behind vehicle	0.0%	2.2%	4.5%	4.2%
SV lane change - left in front of vehicle	0.0%	11.0%	25.7%	24.2%
SV lane change - left other	0.0%	0.0%	1.3%	1.2%
SV lane change - right behind vehicle	0.0%	3.3%	5.4%	5.2%
SV lane change - right in front of vehicle	0.0%	7.7%	16.3%	15.5%
SV lane change - right other	0.0%	0.0%	1.3%	1.2%
Total	100.0%	100.0%	100.0%	100.0%

Table A8. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events by Weather and Severity.

Weather	Severity (N, %)			
	Crash	Near-Crash	Incident	Total
Clear	16 59.26%	356 79.11%	5,762 88.01%	6,134 87.33%
Cloudy	5 18.52%	56 12.44%	429 6.55%	490 6.98%
Raining	5 18.52%	36 8.00%	339 5.18%	380 5.41%
Mist	0 0.00%	1 0.22%	8 0.12%	9 0.13%
Fog	0 0.00%	0 0.00%	5 0.08%	5 0.07%
Snowing	1 3.70%	1 0.22%	1 0.02%	3 0.04%
No analyzed data	0 0.00%	0 0.00%	2 0.03%	2 0.03%
Other	0 0.00%	0 0.00%	1 0.02%	1 0.01%
Total	27 100.00%	450 100.00%	6,547 100.00%	7,024 100.00%

Table A9. Distribution of *Conflict With LV* and *Conflict With FV* Events by Kinematic Precipitating Event, Weather, and Severity.

Kinematic Precipitating Event	Severity				
	Weather	Crash	Near-Crash	Incident	Total
LV Stopped > 2 s	Clear	4	40	1,186	1,230
	Cloudy	0	2	85	87
	Fog	0	0	1	1
	No data	0	0	2	2
	Other	0	0	1	1
	Raining	4	2	56	62
LV Decelerating	Clear	0	129	2,453	2,582
	Cloudy	0	27	179	206
	Fog	0	0	2	2
	Mist	0	0	5	5
	Raining	0	15	155	170
	Snowing	0	1	0	1
SV Stopped > 2 s	Clear	3	0	42	45
	Cloudy	1	0	4	5
	Raining	0	0	2	2
LV Stopped ≤ 2 s	Clear	5	71	959	1,035
	Cloudy	1	10	75	86
	Raining	1	4	55	60
LV Accelerating	Clear	0	0	11	11
	Cloudy	0	1	0	1
	Raining	0	0	1	1
LV Slower Constant Speed	Clear	0	6	117	123
	Cloudy	0	0	5	5
	Mist	0	0	1	1
	Raining	0	0	7	7
	Snowing	0	0	1	1
SV Stopped ≤ 2 s	Clear	2	12	41	55
	Cloudy	1	0	4	5
	Mist	0	1	0	1
	Raining	0	3	1	4
SV Decelerating	Clear	2	19	131	152
	Cloudy	2	0	12	14
	Raining	0	3	10	13
SV Slower Constant Speed	Clear	0	0	12	12
	Cloudy	0	0	4	4
	Raining	0	0	2	2
Total		26	346	5,622	5,994

Table A10. Percentage of *Conflict With LV* and *Conflict With FV* Events by Kinematic Precipitating Event, Weather, and Severity. Percentages within each outlined kinematic category are considered individually (within each category, columns add to 100%).

Kinematic Precipitating Event	Severity				
	Weather	Crash	Near-Crash	Incident	Total
LV Stopped > 2 s	Clear	50.0%	90.9%	89.1%	88.9%
	Cloudy	0.0%	4.5%	6.4%	6.3%
	Fog	0.0%	0.0%	0.1%	0.1%
	No data	0.0%	0.0%	0.2%	0.1%
	Other	0.0%	0.0%	0.1%	0.1%
	Raining	50.0%	4.5%	4.2%	4.5%
LV Decelerating	Clear	0.0%	75.0%	87.8%	87.1%
	Cloudy	0.0%	15.7%	6.4%	6.9%
	Fog	0.0%	0.0%	0.1%	0.1%
	Mist	0.0%	0.0%	0.2%	0.2%
	Raining	0.0%	8.7%	5.5%	5.7%
	Snowing	0.0%	0.6%	0.0%	0.0%
SV Stopped > 2 s	Clear	75.0%	0.0%	87.5%	86.5%
	Cloudy	25.0%	0.0%	8.3%	9.6%
	Raining	0.0%	0.0%	4.2%	3.8%
LV Stopped ≤ 2 s	Clear	71.4%	83.5%	88.1%	87.6%
	Cloudy	14.3%	11.8%	6.9%	7.3%
	Raining	14.3%	4.7%	5.1%	5.1%
LV Accelerating	Clear	0.0%	0.0%	91.7%	84.6%
	Cloudy	0.0%	100.0%	0.0%	7.7%
	Raining	0.0%	0.0%	8.3%	7.7%
LV Slower Constant Speed	Clear	0.0%	100.0%	89.3%	89.8%
	Cloudy	0.0%	0.0%	3.8%	3.6%
	Mist	0.0%	0.0%	0.8%	0.7%
	Raining	0.0%	0.0%	5.3%	5.1%
	Snowing	0.0%	0.0%	0.8%	0.7%
SV Stopped ≤ 2 s	Clear	66.7%	75.0%	89.1%	84.6%
	Cloudy	33.3%	0.0%	8.7%	7.7%
	Mist	0.0%	6.3%	0.0%	1.5%
	Raining	0.0%	18.8%	2.2%	6.2%
SV Decelerating	Clear	50.0%	86.4%	85.6%	84.9%
	Cloudy	50.0%	0.0%	7.8%	7.8%
	Raining	0.0%	13.6%	6.5%	7.3%
SV Slower Constant Speed	Clear	0.0%	0.0%	66.7%	66.7%
	Cloudy	0.0%	0.0%	22.2%	22.2%
	Raining	0.0%	0.0%	11.1%	11.1%

Table A11. Distribution of *Conflict With LV* and *Conflict With FV* Events by Kinematic Precipitating Event, Environmental Light, and Severity.

Kinematic Precipitating Event	Severity				
	Light	Crash	Near-Crash	Incident	Total
LV Stopped > 2 s	Dark, lighted	2	6	186	194
	Dark, not lighted	1	2	40	43
	Dawn	0	0	16	16
	Daylight	4	33	1,004	1,041
	Dusk	1	3	83	87
	No analyzed data	0	0	2	2
LV Decelerating	Dark, lighted	0	35	353	388
	Dark, not lighted	0	11	113	124
	Dawn	0	3	29	32
	Daylight	0	105	2,104	2,209
	Dusk	0	18	194	212
	No analyzed data	0	0	1	1
SV Stopped > 2 s	Dark, lighted	1	0	4	5
	Dark, not lighted	0	0	2	2
	Daylight	3	0	41	44
	Dusk	0	0	1	1
LV Stopped ≤ 2 s	Dark, lighted	1	16	157	174
	Dark, not lighted	0	6	36	42
	Dawn	0	3	11	14
	Daylight	6	51	804	861
	Dusk	0	9	81	90
LV Accelerating	Dark, lighted	0	0	3	3
	Dark, not lighted	0	0	3	3
	Daylight	0	0	5	5
	Dusk	0	1	1	2
LV Slower Constant Speed	Dark, lighted	0	0	10	10
	Dark, not lighted	0	2	5	7
	Dawn	0	0	2	2
	Daylight	0	4	104	108
	Dusk	0	0	10	10
SV Stopped ≤ 2 s	Dark, lighted	0	1	2	3
	Dark, not lighted	0	0	2	2
	Daylight	3	13	37	53
	Dusk	0	2	5	7
SV Decelerating	Dark, lighted	0	2	8	10
	Dark, not lighted	0	1	4	5
	Dawn	0	0	1	1
	Daylight	4	17	128	149
	Dusk	0	2	12	14
SV Slower Constant Speed	Dark, lighted	0	0	1	1
	Dark, not lighted	0	0	1	1
	Dawn	0	0	1	1
	Daylight	0	0	12	12
	Dusk	0	0	3	3
Total		26	346	5,622	5,994

Table A12. Percentage of *Conflict With LV* and *Conflict With FV* Events by Kinematic Precipitating Event, Environmental Light, and Severity. Percentages within each outlined kinematic category are considered individually (within each category, columns add to 100%).

Kinematic Precipitating Event	Severity				
	Light	**Crash**	**Near-Crash**	**Incident**	**Total**
LV Stopped > 2 s	Dark, lighted	25.0%	13.6%	14.0%	14.0%
	Dark, not lighted	12.5%	4.5%	3.0%	3.1%
	Dawn	0.0%	0.0%	1.2%	1.2%
	Daylight	50.0%	75.0%	75.4%	75.3%
	Dusk	12.5%	6.8%	6.2%	6.3%
	No analyzed data	0.0%	0.0%	0.2%	0.1%
LV Decelerating	Dark, lighted	0.0%	20.3%	12.6%	13.1%
	Dark, not lighted	0.0%	6.4%	4.0%	4.2%
	Dawn	0.0%	1.7%	1.0%	1.1%
	Daylight	0.0%	61.0%	75.3%	74.5%
	Dusk	0.0%	10.5%	6.9%	7.1%
	No analyzed data	0.0%	0.0%	0.0%	0.0%
SV Stopped > 2 s	Dark, lighted	25.0%	0.0%	8.3%	9.6%
	Dark, not lighted	0.0%	0.0%	4.2%	3.8%
	Daylight	75.0%	0.0%	85.4%	84.6%
	Dusk	0.0%	0.0%	2.1%	1.9%
LV Stopped ≤ 2 s	Dark, lighted	14.3%	18.8%	14.4%	14.7%
	Dark, not lighted	0.0%	7.1%	3.3%	3.6%
	Dawn	0.0%	3.5%	1.0%	1.2%
	Daylight	85.7%	60.0%	73.8%	72.9%
	Dusk	0.0%	10.6%	7.4%	7.6%
LV Accelerating	Dark, lighted	0.0%	0.0%	25.0%	23.1%
	Dark, not lighted	0.0%	0.0%	25.0%	23.1%
	Daylight	0.0%	0.0%	41.7%	38.5%
	Dusk	0.0%	100.0%	8.3%	15.4%
LV Slower Constant Speed	Dark, lighted	0.0%	0.0%	7.6%	7.3%
	Dark, not lighted	0.0%	33.3%	3.8%	5.1%
	Dawn	0.0%	0.0%	1.5%	1.5%
	Daylight	0.0%	66.7%	79.4%	78.8%
	Dusk	0.0%	0.0%	7.6%	7.3%
SV Stopped ≤ 2 s	Dark, lighted	0.0%	6.3%	4.3%	4.6%
	Dark, not lighted	0.0%	0.0%	4.3%	3.1%
	Daylight	100.0%	81.3%	80.4%	81.5%
	Dusk	0.0%	12.5%	10.9%	10.8%
SV Decelerating	Dark, lighted	0.0%	9.1%	5.2%	5.6%
	Dark, not lighted	0.0%	4.5%	2.6%	2.8%
	Dawn	0.0%	0.0%	0.7%	0.6%
	Daylight	100.0%	77.3%	83.7%	83.2%
	Dusk	0.0%	9.1%	7.8%	7.8%
SV Slower Constant Speed	Dark, lighted	0.0%	0.0%	5.6%	5.6%
	Dark, not lighted	0.0%	0.0%	5.6%	5.6%
	Dawn	0.0%	0.0%	5.6%	5.6%
	Daylight	0.0%	0.0%	66.7%	66.7%
	Dusk	0.0%	0.0%	16.7%	16.7%

Table A13. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events by Road Alignment and Severity.

Road Alignment	Severity (N, %)			
	Crash	**Near-Crash**	**Incident**	**Total**
Straight level	20 74.07%	391 86.89%	6,007 91.75%	6,418 91.37%
Curve level	6 22.22%	49 10.89%	431 6.58%	486 6.92%
Straight grade	0 0.00%	9 2.00%	64 0.98%	73 1.04%
Curve Grade	1 3.70%	1 0.22%	29 0.44%	31 0.44%
Straight Hillcrest	0 0.00%	0 0.00%	10 0.15%	10 0.14%
Curve Hillcrest	0 0.00%	0 0.00%	2 0.03%	2 0.03%
No analyzed data	0 0.00%	0 0.00%	4 0.06%	4 0.06%
Total	27 100.00%	450 100.00%	6,547 100.00%	7,024 100.00%

Table A14. Distribution of *Conflict With LV* and *Conflict With FV* Events by Relation to Junction and Severity.

Relation to Junction	Severity			
	Crash	**Near-Crash**	**Incident**	**Total**
Non-Junction	9	309	4,077	4,395
Intersection-related	8	53	1,632	1,693
Intersection	5	49	432	486
Entrance/exit ramp	5	18	230	253
Driveway, alley access, etc.	0	4	84	88
Interchange area	0	11	54	65
Parking lot	0	5	26	31
Rail grade crossing	0	0	2	2
Other	0	1	4	5
No analyzed data	0	0	6	6
Total	27	450	6,547	7,024

Table A15. Percentage of *Conflict With LV* and *Conflict With FV* Events by Relation to Junction and Severity.

Relation to Junction	Severity			
	Crash	Near-Crash	Incident	Total
Non-Junction	33.3%	68.7%	62.3%	62.6%
Intersection-related	29.6%	11.8%	24.9%	24.1%
Intersection	18.5%	10.9%	6.6%	6.9%
Entrance/exit ramp	18.5%	4.0%	3.5%	3.6%
Driveway, alley access, etc.	0.0%	0.9%	1.3%	1.3%
Interchange area	0.0%	2.4%	0.8%	0.9%
Parking lot	0.0%	1.1%	0.4%	0.4%
Rail grade crossing	0.0%	0.0%	0.0%	0.0%
Other	0.0%	0.2%	0.1%	0.1%
No analyzed data	0.0%	0.0%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%

Table A16. Distribution of *Conflict With LV* and *Conflict With FV* Events by Locality and Severity.

Locality	Severity			
	Crash	Near-Crash	Incident	Total
Business/industrial	16	188	3,083	3,287
Interstate	6	155	1,659	1,820
Open Country	3	71	902	976
Residential	1	30	769	800
Construction Zone	1	4	98	103
Other	0	2	12	14
School	0	0	13	13
Church	0	0	4	4
No analyzed data	0	0	7	7
Total	27	450	6,547	7,024

Table A17. Percentage of *Conflict With LV* and *Conflict With FV* Events by Locality and Severity.

Locality	Severity			
	Crash	Near-Crash	Incident	Total
Business/industrial	59.3%	41.8%	47.1%	46.8%
Interstate	22.2%	34.4%	25.3%	25.9%
Open Country	11.1%	15.8%	13.8%	13.9%
Residential	3.7%	6.7%	11.7%	11.4%
Construction Zone	3.7%	0.9%	1.5%	1.5%
Other	0.0%	0.4%	0.2%	0.2%
School	0.0%	0.0%	0.2%	0.2%
Church	0.0%	0.0%	0.1%	0.1%
No analyzed data	0.0%	0.0%	0.1%	0.1%
Total	100.0%	100.0%	100.0%	100.0%

Table A18. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events by Traffic Flow/Density and Severity.

Traffic Flow/Density	Severity (N, %)			
	Crash	Near-Crash	Incident	Total
Flow with some restrictions	8 29.6%	148 32.9%	2,947 45.0%	3,103 44.2%
Stable flow, more restricted maneuverability, speed	4 14.8%	132 29.3%	1,860 28.4%	1,996 28.4%
Unstable flow, temporary restrictions	3 11.1%	53 11.8%	913 13.9%	969 13.8%
Free flow	9 33.3%	94 20.9%	525 8.0%	628 8.9%
Unstable flow, significant restrictions	2 7.4%	21 4.7%	291 4.4%	314 4.5%
Forced traffic flow with low speeds, below capacity traffic volumes	1 3.7%	2 0.4%	7 0.1%	10 0.1%
No analyzed data	0 0.0%	0 0.0%	4 0.1%	4 0.1%
Total	27 100.0%	450 100.0%	6,547 100.0%	7,024 100.0%

Table A19. Distribution and Percentage of *Conflict With LV* and *Conflict With FV* Events By Traffic Flow/Density and Severity for Which a Distraction was Coded.

Traffic Flow/Density	Severity (N, %)			
	Crash	Near-crash	Incident	Total
Flow with some restrictions	5 62.5%	64 43.2%	719 24.4%	788 25.4%
Stable flow, more restricted maneuverability, speed	2 50.0%	52 39.4%	454 24.4%	508 25.5%
Unstable flow, temporary restrictions	2 66.7%	26 49.1%	189 20.7%	217 22.4%
Free flow	6 66.7%	33 35.1%	96 18.3%	135 21.5%
Unstable flow, significant restrictions	2 100%	9 42.9%	80 27.5%	91 29.0%
Forced traffic flow with low speeds, below capacity traffic volumes	1 100%	0 0.0%	3 42.9%	4 40.0%
No analyzed data	0 0.0%	0 0.0%	2 50.0%	2 50.0%
Total	18 66.7%	184 40.9%	1,543 23.6%	1,745 24.8%

Table A20. Distribution of *Conflict With LV* and *Conflict With FV* Events by Pre-Incident Maneuver and Severity.

	Severity			
Pre-Incident Maneuver	**Crash**	**Near-Crash**	**Incident**	**Total**
Going straight, constant speed	3	201	2,856	3,060
Decelerating in traffic lane	12	104	2,019	2,135
Going straight, accelerating	3	68	1,034	1,105
Changing lanes	0	43	358	401
Negotiating a curve	0	5	87	92
Starting in traffic lane	2	7	77	86
Stopped in traffic lane	3	10	51	64
Merging	3	6	20	29
Turning left	0	4	21	25
Turning right	0	1	13	14
Going straight with unintentional drift	0	0	7	7
Maneuvering to avoid a vehicle	0	1	2	3
Entering a parked position	1	0	0	1
Other	0	0	1	1
Unknown	0	0	1	1
Total	27	450	6,547	7,024

Table A21. Percentage of *Conflict With LV* and *Conflict With FV* Events by Pre-Incident Maneuver and Severity.

	Severity			
Pre-Incident Maneuver	**Crash**	**Near-Crash**	**Incident**	**Total**
Going straight, constant speed	11.1%	44.7%	43.6%	43.6%
Decelerating in traffic lane	44.4%	23.1%	30.8%	30.4%
Going straight, accelerating	11.1%	15.1%	15.8%	15.7%
Changing lanes	0.0%	9.6%	5.5%	5.7%
Negotiating a curve	0.0%	1.1%	1.3%	1.3%
Starting in traffic lane	7.4%	1.6%	1.2%	1.2%
Stopped in traffic lane	11.1%	2.2%	0.8%	0.9%
Merging	11.1%	1.3%	0.3%	0.4%
Turning left	0.0%	0.9%	0.3%	0.4%
Turning right	0.0%	0.2%	0.2%	0.2%
Going straight with unintentional drift	0.0%	0.0%	0.1%	0.1%
Maneuvering to avoid a vehicle	0.0%	0.2%	0.0%	0.0%
Entering a parked position	3.7%	0.0%	0.0%	0.0%
Other	0.0%	0.0%	0.0%	0.0%
Unknown	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%

Table A22. Distribution of *Conflict With LV* and *Conflict With FV* Events by Pre-Incident Maneuver, Maneuver Judgment, and Severity.

Pre-Incident Maneuver	Maneuver Judgment	Severity			
		Crash	Near-Crash	Incident	Total
Going straight, constant speed	Safe and legal	3	190	2,759	2,952
	Safe but illegal	0	1	23	24
	Unsafe and illegal	0	6	26	32
	Unsafe but legal	0	4	48	52
Decelerating in traffic lane	No analyzed Data	0	0	2	2
	Safe and legal	11	102	1,959	2,072
	Safe but illegal	0	0	5	5
	Unsafe and illegal	0	0	6	6
	Unsafe but legal	1	2	47	50
Going straight, accelerating	No analyzed Data	0	0	1	1
	Safe and legal	2	65	963	1,030
	Safe but illegal	0	0	4	4
	Unsafe and illegal	0	1	10	11
	Unsafe but legal	1	2	56	59
Changing lanes	No analyzed Data	0	0	1	1
	Safe and legal	0	24	249	273
	Safe but illegal	0	0	16	16
	Unknown	0	1	0	1
	Unsafe and illegal	0	12	44	56
	Unsafe but legal	0	6	48	54
Negotiating a curve	Safe and legal	0	5	85	90
	Unsafe and illegal	0	0	1	1
	Unsafe but legal	0	0	1	1
Starting in traffic lane	Safe and legal	2	7	74	83
	Unsafe but legal	0	0	3	3
Stopped in traffic lane	Safe and legal	3	8	50	61
	Unsafe and illegal	0	1	1	2
	Unsafe but legal	0	1	0	1
Merging	No analyzed Data	0	1	0	1
	Safe and legal	3	2	18	23
	Unsafe and illegal	0	1	0	1
	Unsafe but legal	0	2	2	4
Turning left	Safe and legal	0	4	19	23
	Safe but illegal	0	0	1	1
	Unsafe and illegal	0	0	1	1
Turning right	Safe and legal	0	1	13	14
Going straight with unintentional drift	Safe and legal	0	0	3	3
	Unsafe and illegal	0	0	4	4
Maneuvering to avoid a vehicle	Safe and legal	0	1	0	1
	Unsafe and illegal	0	0	1	1
	Unsafe but legal	0	0	1	1
Entering a parked position	Safe and legal	1	0	0	1
Other	Safe and legal	0	0	1	1
Unknown	Safe and legal	0	0	1	1
Total		27	450	6,547	7,024

Table A23. Percentage of Conflict With LV and Conflict With FV Events by Pre-Incident Maneuver, Maneuver Judgment, and Severity. Percentages within each outlined pre-incident maneuver category are considered individually (within each category, columns add to 100%).

Pre-Incident Maneuver	Maneuver Judgment	Severity			
		Crash	Near-Crash	Incident	Total
Going straight, constant speed	Safe and legal	100.0%	94.5%	96.6%	96.5%
	Safe but illegal	0.0%	0.5%	0.8%	0.8%
	Unsafe and illegal	0.0%	3.0%	0.9%	1.0%
	Unsafe but legal	0.0%	2.0%	1.7%	1.7%
Decelerating in traffic lane	No analyzed Data	0.0%	0.0%	0.1%	0.1%
	Safe and legal	91.7%	98.1%	97.0%	97.0%
	Safe but illegal	0.0%	0.0%	0.2%	0.2%
	Unsafe and illegal	0.0%	0.0%	0.3%	0.3%
	Unsafe but legal	8.3%	1.9%	2.3%	2.3%
Going straight, accelerating	No analyzed Data	0.0%	0.0%	0.1%	0.1%
	Safe and legal	66.7%	95.6%	93.1%	93.2%
	Safe but illegal	0.0%	0.0%	0.4%	0.4%
	Unsafe and illegal	0.0%	1.5%	1.0%	1.0%
	Unsafe but legal	33.3%	2.9%	5.4%	5.3%
Changing lanes	No analyzed Data	0.0%	0.0%	0.3%	0.2%
	Safe and legal	0.0%	55.8%	69.6%	68.1%
	Safe but illegal	0.0%	0.0%	4.5%	4.0%
	Unknown	0.0%	2.3%	0.0%	0.2%
	Unsafe and illegal	0.0%	27.9%	12.3%	14.0%
	Unsafe but legal	0.0%	14.0%	13.4%	13.5%
Negotiating a curve	Safe and legal	0.0%	100.0%	97.7%	97.8%
	Unsafe and illegal	0.0%	0.0%	1.1%	1.1%
	Unsafe but legal	0.0%	0.0%	1.1%	1.1%
Starting in traffic lane	Safe and legal	100.0%	100.0%	96.1%	96.5%
	Unsafe but legal	0.0%	0.0%	3.9%	3.5%
Stopped in traffic lane	Safe and legal	100.0%	80.0%	98.0%	95.3%
	Unsafe and illegal	0.0%	10.0%	2.0%	3.1%
	Unsafe but legal	0.0%	10.0%	0.0%	1.6%
Merging	No analyzed Data	0.0%	16.7%	0.0%	3.4%
	Safe and legal	100.0%	33.3%	90.0%	79.3%
	Unsafe and illegal	0.0%	16.7%	0.0%	3.4%
	Unsafe but legal	0.0%	33.3%	10.0%	13.8%
Turning left	Safe and legal	0.0%	100.0%	90.5%	92.0%
	Safe but illegal	0.0%	0.0%	4.8%	4.0%
	Unsafe and illegal	0.0%	0.0%	4.8%	4.0%
Turning right	Safe and legal	0.0%	100.0%	100.0%	100.0%
Going straight with unintentional drift	Safe and legal	0.0%	0.0%	42.9%	42.9%
	Unsafe and illegal	0.0%	0.0%	57.1%	57.1%
Maneuvering to avoid a vehicle	Safe and legal	0.0%	100.0%	0.0%	33.3%
	Unsafe and illegal	0.0%	0.0%	50.0%	33.3%
	Unsafe but legal	0.0%	0.0%	50.0%	33.3%
Entering a parked position	Safe and legal	100.0%	0.0%	0.0%	100.0%
Other	Safe and legal	0.0%	0.0%	100.0%	100.0%
Unknown	Safe and legal	0.0%	0.0%	100.0%	100.0%

Table A24. Distribution of *Conflict With LV* and *Conflict With FV* Events by Driver Impairment and Severity.

Driver Impairments	Severity			
	Crash	Near-Crash	Incident	Total
None apparent	10	217	4,499	4,726
Distracted	12	165	1,407	1,584
Drowsy, fatigued, asleep	2	47	474	523
Unknown	2	12	100	114
Angry	0	6	29	35
Other emotional state	0	3	12	15
Impaired due to previous injury	0	0	4	4
Drugs, alcohol	1	0	0	1
Other	0	0	17	17
No analyzed data	0	0	5	5
Total	27	450	6,547	7,024

Table A25. Percentage of *Conflict With LV* and *Conflict With FV* Events by Driver Impairment and Severity.

Driver Impairments	Severity			
	Crash	Near-Crash	Incident	Total
None apparent	37.04%	48.22%	68.72%	67.28%
Distracted	44.44%	36.67%	21.49%	22.55%
Drowsy, fatigued, asleep	7.41%	10.44%	7.24%	7.45%
Unknown	7.41%	2.67%	1.53%	1.62%
Angry	0.00%	1.33%	0.44%	0.50%
Other emotional state	0.00%	0.67%	0.18%	0.21%
Impaired due to previous injury	0.00%	0.00%	0.06%	0.06%
Drugs, alcohol	3.70%	0.00%	0.00%	0.01%
Other	0.00%	0.00%	0.26%	0.24%
No analyzed data	0.00%	0.00%	0.08%	0.07%
Total	100.00%	100.00%	100.00%	100.00%

Table A26. Distribution of *Conflict With LV* and *Conflict With FV* Events by Driver Impairments, Driver Proficiency, and Severity.

Driver Impairments	Driver Proficiency	Severity			
		Crash	Near-Crash	Incident	Total
None apparent	Driver capabilities	0	0	8	8
	Driving techniques	3	86	2,490	2,579
	Competent	7	128	1,978	2,113
	Vehicle kinematics	0	3	11	14
	Violation of traffic laws	0	0	12	12
	Total	**10**	**217**	**4,499**	**4,726**
Distracted	Driver capabilities	0	0	3	3
	Driving techniques	1	88	934	1,023
	Competent	11	72	465	548
	Vehicle kinematics	0	2	3	5
	Violation of traffic laws	0	3	2	5
	Total	**12**	**165**	**1,407**	**1,584**
Drowsy, fatigued, asleep	Driving techniques	1	27	328	356
	Competent	1	19	144	164
	Vehicle kinematics	0	0	2	2
	Violation of traffic laws	0	1	0	1
	Total	**2**	**47**	**474**	**523**
Unknown	Driver capabilities	0	0	1	1
	Driving techniques	0	5	77	82
	Competent	2	7	22	31
	Total	**2**	**12**	**100**	**114**
Angry	Driving techniques	0	0	8	8
	Competent	0	6	19	25
	Vehicle kinematics	0	0	1	1
	Violation of traffic laws	0	0	1	1
	Total	**0**	**6**	**29**	**35**
Grand Total		**27**	**450**	**6,547**	**7,024**

Table A27. Percentage of *Conflict With LV* and *Conflict With FV* Events by Driver Impairments, Driver Proficiency, and Severity.

Driver Impairments	Driver Proficiency	Severity			
		Crash	Near-Crash	Incident	Total
None apparent	Driver capabilities	0.0%	0.0%	0.2%	0.2%
	Driving techniques	30.0%	39.6%	55.3%	54.6%
	Competent	70.0%	59.0%	44.0%	44.7%
	Vehicle kinematics	0.0%	1.4%	0.2%	0.3%
	Violation of traffic laws	0.0%	0.0%	0.3%	0.3%
	Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Distracted	Driver capabilities	0.0%	0.0%	0.2%	0.2%
	Driving techniques	8.3%	53.3%	66.4%	64.6%
	Competent	91.7%	43.6%	33.0%	34.6%
	Vehicle kinematics	0.0%	1.2%	0.2%	0.3%
	Violation of traffic laws	0.0%	1.8%	0.1%	0.3%
	Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Drowsy, fatigued, asleep	Driving techniques	50.0%	57.4%	69.2%	68.1%
	Competent	50.0%	40.4%	30.4%	31.4%
	Vehicle kinematics	0.0%	0.0%	0.4%	0.4%
	Violation of traffic laws	0.0%	2.1%	0.0%	0.2%
	Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Unknown	Driver capabilities	0.0%	0.0%	1.0%	0.9%
	Driving techniques	0.0%	41.7%	77.0%	71.9%
	Competent	100.0%	58.3%	22.0%	27.2%
	Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Angry	Driving techniques	0.0%	0.0%	27.6%	22.9%
	Competent	0.0%	100.0%	65.5%	71.4%
	Vehicle kinematics	0.0%	0.0%	3.4%	2.9%
	Violation of traffic laws	0.0%	0.0%	3.4%	2.9%
	Total	**0.0%**	**100.0%**	**100.0%**	**100.0%**

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