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A Cloud-based Solutions to Commercial Driver Hazard Perception Training and Screening

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List of Terms and Abbreviations

AOI – area of interest

CDATS - Commercial Driver Assessment & Training System

CMV – commercial motor vehicle

FOV – field-of-view

HD – hazard detection

IVL – interactive video lesson

LTCCS – Large Truck Crash Causation Study

MCMIS - Motor Carrier Management Information System

MDN – median

SD – standard deviation

SEEV – salience, effort, expectancy, & value

STI – Systems Technology, Inc.

SUT – single-unit truck

VTTI – Virginia Tech Transportation Institute

Abstract

Project Title: A Computer-Based Training Approach to Reducing Commercial Driver Crashes and Injuries

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Motor vehicle crashes are the leading cause of work-related fatalities in the U.S. and costs employers $60 billion annually. However, few studies have assessed the hazard detection (HD) challenges of experienced, skilled drivers. This paper presents the pilot study results of a HD training program, the Commercial Driver Assessment & Training System (CDATS), developed for commercial motor vehicle (CMV) drivers. The training involved simulation-based videos that highlight potential vehicle, pedestrian, and visually hidden hazards during unprotected intersection maneuvers: left-turn, right-turn, and straight-thru. Low-fidelity, driving simulations were designed to reinforce video lessons and increase the expectation and detection of potential hazards. A CDATS prototype was evaluated using a driving simulator HD task presented to a sample of 16 short-haul, single-unit truck, CMV drivers before and after random assignment to CDATS training or a control group. Results provided two key findings. First, experienced, CMV drivers can also exhibit poor HD skills—particularly for visually hidden and visible pedestrian hazards—and may benefit from HD training. Second, the CDATS program showed potential to improve HD skills for CMV drivers during unprotected intersection maneuvers. Post-training results suggested overall HD improvement in the CDATS training group with no change in the control group. Results of this project highlight the traffic safety needs of CMV drivers and informs the development of future CMV driver safety and training interventions.

Section 1: Summary

Although motor vehicle crashes remain the leading cause of death among U.S. workers (FMCSA, 2014) and issues related to driving hazard detection (HD) are the most common contributors to commercial motor vehicle (CMV) crashes (Blower & Campbell, 2005), HD skills training has historically been considered a novice (age 16-24) or older driver (age 65+) problem. Yet, research shows that even middle-aged drivers with decades of driving experience can exhibit sub-optimal HD skills due to a lack of self-awareness and corrective feedback (Horswill, Taylor, Newnam, Wetton, & Hill, 2013).

Proactive, traffic safety programs with driving simulation-based training provides an attractive means of improving HD skills and supplementing traditional training methods. However, the CMV industry needs are broad and simulation solutions are often costly and unwieldly to deploy as high turnover rates overwhelm industry training and screening needs.

To meet the traffic safety and training needs of CMV carriers, this Phase I SBIR proposed the development and validation of the Commercial Driver Assessment & Training System (CDATS): a cloud-based, CMV driver training system that uses multimedia instruction and innovated driving simulation techniques to supplement traditional, driver job training and increase the HD skills of CMV drivers. Executed by team members from Systems Technology, Inc. (STI) and the Virginia Tech Transportation Institute (VTTI), the specific project aims included: 1) set curriculum requirement of CDATS, 2) develop a CDATS prototype, 3) evaluate the training potential of CDATS using a sample of 16 CMV drivers, and 4) analyze and interpret the study results.

Significant or Key Findings

To assess the HD training potential of CDATS, a pilot-training study was performed using a sample of experienced, short-haul, single-unit truck (SUT) CMV drivers, $N = 16$. HD performance (HD task accuracy, % correct) was measured using a wide-FOV driving simulator and HD task composed of potential hazards (e.g., vehicle, pedestrian, and visually hidden hazards) during unprotected, intersection maneuvers (left-turn, right-turn, and straight-thru). The HD task was presented to participants before random assignment to either the CDATS training or control group (pre-test) and 1-week later (post-test). The control group was provided driving scenarios designed for training novice drivers on collision avoidance.

Two key findings were found. First, in accordance to prior studies (Horswill et al., 2013), experienced, CMV drivers can also exhibit poor HD skills—particularly for visually hidden and visible pedestrian hazards—and may benefit from HD training. Few studies have examined SUT drivers (e.g., package delivery), a significant subgroup of CMV drivers that do not always receive the same level of training as long-haul truck drivers.

Second, the CDATS program showed potential to improve HD skills for CMV drivers during unprotected intersection maneuvers. At pre-test, no group differences were observed for HD task accuracy. At post-test, CDATS trained drivers improved their HD task accuracy compared to the control. Control group drivers did not appear to benefit from novice driver oriented scenarios. The results suggest that CMV drivers may benefit more from cognitive-based training programs for HD as opposed to simulation training typically provided to beginning drivers.

Translation of Findings

The CDATS program remains in the development stage. However, significant progress has been made in understanding CMV driver needs and training solutions. Since HD training is historically directed towards younger, novice drivers, little is known regarding the specific types of hazards and situations in which CMV drivers find the most challenging, and the best methods

for improving or maintaining HD skills. In other words, “How do you get experienced, skilled drivers to begin attending to different hazardous areas to improve their overall situational awareness?”

Our training results suggest that CMV driver training is needed for certain kinds of hazards such as those involving pedestrians and visual obstruction of threats. Furthermore, this training may be achieved using low-cost simulation solutions that CMV operations are more likely to employ. We plan on proposing a future project that: 1) expands the current CDATS curriculum with new driving situations, 2) develops an improved and innovative means of presenting hazards to trainees that does not require actual driving simulator hardware, and 3) validating the new design in larger sampled study that includes on-road, instrumented vehicle tests.

Research Outcomes/Impact

CDATS and similar HD skills training inventions can potentially meet the traffic safety and training needs of commercial motor vehicle (CMV) carriers where vehicle crashes are the leading cause of work-related fatalities in the U.S. and costs employers $60 billion annually in medical care, legal expenses, property damage, and lost productivity (NHTSA, 2003).

By focusing on perceptual- and cognitive-based HD skills for everyday driving environments the CDATS program: 1) addresses the main contributor to crashes and is applicable to a broad range of CMV operations and drivers, and 2) a simulator station could use inexpensive, off-the-shelf, driver controls or potentially no driver controls at all, if designed correctly. By integrating low-cost, driving simulation technology with a cloud-based data solution, simulation-based training can be deployed in a cost-effective manner and used anywhere there is internet service. Training curriculum materials and driver assessment/training data (e.g., survey and HD performance) are now accessible online for management, tracking, normative data analysis, and system updates.

Section 2: Scientific Report

Introduction

Motor vehicle crashes remain the leading cause of death among U.S. workers in an industry that includes more than 539,000 active motor carriers and 5.6 million CMV drivers (FMCSA, 2014) and costs employers $60 billion annually in medical care, legal expenses, property damage, and lost productivity (NHTSA, 2003). Studies such as the Large Truck Crash Causation Study (LTCCS) have found crashes are overwhelmingly caused by human error (89% human, 8% vehicle, and 3% roadway environment) with the most common human error types to be related to a lack of driving hazard detection (HD) and situational awareness: 38% driver decision error (e.g., too fast for conditions), 29% driver recognition failure (e.g., inattention), and 12% driver physical failure (e.g., sleep-at-the-wheel) (Blower & Campbell, 2005). The LTCCS data also shows that for entry-level truck drivers with fewer than 5 years of experience, the risk of being assigned the critical reason/cause for the crash is 17% higher than that of drivers with 5 or more years of experience (FMCSA, 2017).

A driving hazard can be defined as anything (e.g., vehicle, pedestrian, object) or situation (e.g., visual obscurity, roadway condition) that may result in a collision; requiring anticipatory or evasive action by the driver (e.g., brake pedal covering, speed reduction, or steering). Historically considered a novice driver (aged 16-24) or older driver (aged 65+) problem due to their higher crash rates (IIHS, 2015), a driver's lack of HD skill is associated with increased crash risk (Boufous, Ivers, Senserrick, & Stevenson, 2011; Horswill, Anstey, Hatherly, & Wood, 2010). Unlike older drivers who may be dealing with age-related deficits, novice drivers are thought to exhibit poorer HD skills due to inexperience, with the idea that HD skills eventually develop as drivers gain maturity and exposure. Although CMV drivers represent a professional subset of the driving population that are likely better trained and skilled, research indicates that even middle-aged drivers with decades of driving experience can exhibit sub-optimal HD skills due to a lack of self-awareness and corrective feedback (Horswill et al., 2013). Furthermore, research analyzing the safety performance of 17,000 entry-level CMV drivers with less than 18 mo. of experience, found that nearly 30% of them (despite mean and median age of 38 yrs.) will be involved in a safety incident (25% in property damage only, 4.7% traffic violation, 2.4% DOT reportable crash) (ATRI, 2008).

CMV Driver Training Using Simulation Technology

Proactive, HD-focused, traffic safety programs presented to employee drivers at initial training and throughout a driver's career are potentially one of the best ways to prevent and control costs from workplace crashes. While reactive training methods (e.g., evasive maneuvering/braking) are important, they are not as effective as preventing risky crash situations in the first place. By focusing on perceptual- and cognitive-based HD skills, drivers may initiate pre-event behaviors (e.g., speed, headway, gap acceptance, braking) to reduce crash risks. Since HD training is historically directed towards younger novice drivers, little is known regarding the specific types of hazards and situations in which CMV drivers find the most challenging, and the best methods for improving or maintaining HD skills. In other words, "How do you get experienced, skilled drivers to begin attending to different hazardous areas to improve their overall situational awareness?"

Driving simulation technology provides an attractive solution as a means of implementing a HD training program. Simulation allows perceptual, cognitive, psychomotor, and behavioral tendencies to be trained and assessed. Both anticipatory and reactive training methods are also explorable. The many complementary advantages of simulation technology to traditional classroom and on-road instruction include: safety, scenario versatility, standardization, thoroughness, repeatability, improved perspectives, sophisticated measurement, and efficiency (Rogers & Knipling, 2007).

Unfortunately, several challenges exist for simulation-based training programs. First, effective simulations can be expensive to develop when the needs of the industry are so broad. CMV operations can be small—a single vehicle, owned and operated by a single individual; or large—a corporation that owns tens of thousands of vehicles. Operations can differ in terms of what cargo they deliver (e.g., freight, passenger, hazardous materials), where they operate (e.g., locally, regionally, cross country), when they operate (day, night, seasonal), and the number of destination points (e.g., truckload or less-than-truckload) (GAO, 2015).

Second, simulation-based training can be difficult to deploy in a cost-effective manner. Despite a five-year low, the turnover rate remains remarkably high for the CMV industry; 74% for large and 66% for small truckload carriers (American Trucking Associations, 2017). For larger carriers with thousands of existing drivers and high turnover rates, deploying simulation-based training programs can be unwieldly to manage, time consuming, and impractical to implement fleet-wide regardless of the system's proven effectiveness. Similarly, for smaller carriers the costs may be too prohibitive, particularly if specialized simulation hardware (e.g., driver display/controls, seating, etc.) and support structures (e.g., trained instructors, classroom space) are required. It remains unclear the level of realism a simulator must provide if the training goals are focused on perceptual- and cognitive-based HD skills. If the benefits of simulation technology can be utilized without the need of driving controls, the associated costs and logistics of training could be dramatically reduced, allowing the use of alternative platforms (e.g., laptops and tablets; home-based learning).

Finally, even when the above challenges are met, the resulting performance data is not easily interpretable. With the discrepancy in simulation hardware and scenario design, standardized tests and normative data for simulation performance remains elusive in the field of driver assessment and training.

Specific Aim 1: Set Requirements for CDATS

The CDATS curriculum content was determined using an expanded literature review and dataset analysis of Motor Carrier Management Information System (MCMIS). The targeted sub-population of CMV drivers were short-haul drivers using single-unit trucks (SUTs), a class of medium and heavy trucks in which the engine, cab, drivetrain and cargo area are all mounted on a single chassis, e.g., UPS delivery truck. This subclass of CMV drivers were targeted because: 1) little is known regarding the traffic safety training needs of this group; no specific driving certifications are required to operate such vehicles, 2) low-fidelity simulation may better suit SUTs compared to multi-bodied, long-haul trucks with significant driver control/dashboard differences to passenger vehicles, and 3) market research into fleet operations have indicated a potential training need.

Results of the analysis indicated that SUTs appeared to have traffic safety issues more in common with passenger vehicles than with multi-bodied, long-haul trucks. Most problematic situations involved intersections where pedestrians and traffic intersect. This may have been due to short-haul nature of SUT operations, largely within urban environments to deliver goods or provide services. Issues related to fatigue, substance abuse and cell phone distraction were not deemed as significant compared to addressing the potential attentional deficits related to HD skills. Details of the review are provided in Appendix A.

Additional elements of the CDATS program such as: 1) increasing awareness of driver distraction, fatigue and impairment and 2) job and vehicle specific hazard training, were originally planned, but suspended as grant work progressed. The main obstacle to this was the securing of a single CMV carrier and driver sample. Since CMV drivers were recruited from a variety of sources, a single vehicle design and display environment for driver training was not possible. In addition, policies related to driver distraction, fatigue, and impairment could not be uniform. These obstacles led to focusing on a core curriculum for CDATS that involves a broader approach to CMV HD skills training; potentially applicable to a variety of CMV driver operations.

Specific Aim 2: Develop CDATS Training Content

A CDATS prototype was successfully achieved in Phase I. Provided below is the theoretical model employed for HD skill training and the CDATS training approach.

The SEEV Model for Hazard Detection

A useful framework for understanding why a CMV driver is exhibiting sub-optimal HD skills is the SEEV model of visual information sampling (Wickens & McCarley, 2007). According to the SEEV model, the probability of a skilled driver to selectively attend to or sample sources of information from an area of interest (AOI), is influenced by the combined factors: Salience, Effort, Expectancy, and Value (SEEV). Salience refers to an AOI's ability to capture or grab attention (e.g., flashing lights). Effort refers to the amount of resources needed to access the information at the AOI including physical (e.g., visual angles for head-eye movements) and mental workloads (e.g., concurrent tasks). Increases in salience leads to increases in AOI attention, while increases in effort leads to an inhibitory effect in AOI attention. Both salience and effort are bottom-up or environmentally driven forces; often out of the control of the driver. Expectancy refers to the frequency or probability of seeing relevant information in an AOI. Value refers to the importance—or cost of missing—the information from an AOI to the task(s) at hand. Increases in expectancy and value lead to increases in AOI attention. Both factors are top-down or knowledge driven forces; related to driver experience and situational awareness. Utilized in modeling the visual scanning behavior of operators in aviation (Wickens, Goh, Helleberg, Horrey, & Talleur, 2003; Wickens et al., 2008) and driving (Horrey, Wickens, & Consalus, 2006), the SEEV model can potentially explain the visual attention differences between novice and expert drivers, and the effects of driver state, task workload, and environmental contexts.

Applied to CMV driver HD training, the SEEV model guides how to improve a proficiently, skilled driver into a better driver or alternatively, maintain a more appropriate state of vigilance for high value hazards while driving. This can potentially be achieved by increasing or maintaining the *expectancy* and *value* factors for hazards. For example, consider a situation where a large truck is parked on the right side of the roadway at a pedestrian crossing. On approach, novice drivers often fail to look towards the truck even though their visual field will be vulnerable to crossing pedestrians, hidden from the right (Fisher & Pollatsek, 2007). Their expectation of a pedestrian hazard risk is low. As novice drivers gain roadway experience, their expectation of a pedestrian risk at that crossing appropriately increases, making it more likely that they look towards the truck. However, experienced drivers may *decrease* their expectation and value for the *same* hazardous situation if their continued experience proves that no pedestrians ever cross. As such, experienced drivers may eventually stop looking towards that hazardous truck and be unprepared for pedestrian crosses. The rarity of some hazards during every day driving may ill-prepare experienced drivers when those hazards do inevitably occur.

CDATS Training Approach

The CDATS HD training approach involves several elements designed to increase the SEEV model factors of expectation and value for potential hazards. It is also designed to convey the breadth of potential hazards to spread attention across the driver's visual field, as opposed to focusing on specific critical hazards that experienced drivers likely already respond to. This may in turn lead to greater situational awareness and drivers responding more quickly with appropriate pre-event behaviors. Major training components of CDATS are as follows.

Focus & Breakdown of High-Risk Maneuvers

CDATS currently focuses HD training for short-haul CMV drivers during high-risk vehicle maneuvers where traffic and pedestrians intersect. Prior naturalistic driving studies for short-haul trucks have indicated the most common incidents involve: lane change without sufficient gap, roadway entrance without sufficient clearance, and left-turn without clearance (Hanowski, Hickman, Wierwille, & Keisler, 2007). These situations involve a high number of AOIs where drivers must distribute their attention across the driving scene. The maneuvers addressed by CDATS are left-turns, right-turns, and straight-thru at unprotected intersections (i.e., no dedicated turn signal arrow/lane). Each of these maneuvers are further broken-down into three zones where hazards may appear (**Figure 1**):

- **Pre-maneuver:** preparation period for the maneuver (e.g., driver changes lanes to make a left-turn 200 ft prior to the intersection). Hazards such as pedestrian crossings may be similar for different maneuvers depending on driver vehicle positioning.
- **Maneuver:** execution period for maneuver (e.g., driver executes a left-turn across oncoming traffic and pedestrians at the left-side crosswalk). Hazards are unique to maneuver.
- **Post-maneuver:** stabilization period immediately after the maneuver (e.g., after a wide right-turn, driver moves back to far, right lane). Similar to pre-maneuver hazards, but locations are subject to the maneuver. Requires most anticipation and situational awareness since it occurs quickly after maneuver execution and may involve overlap with the next pre-maneuver period.

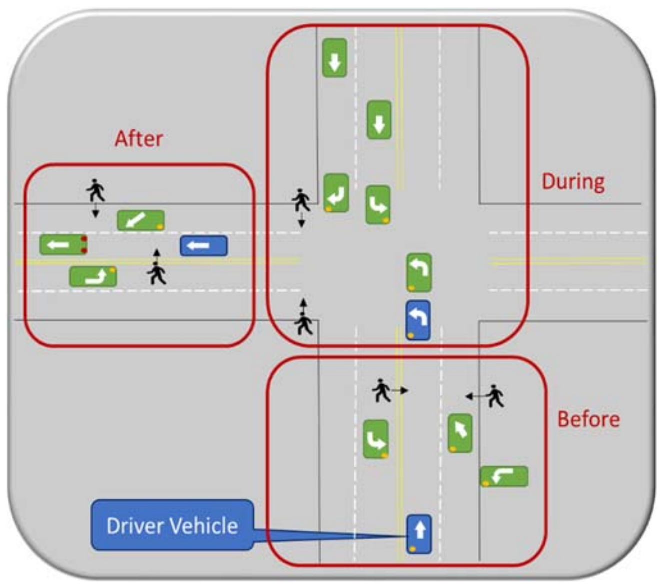


Figure 1. Intersection breakdown of pedestrian and vehicle hazards by 3 zones (red boxes) during an unprotected, left-turn maneuver.

Video & Simulation Techniques to Visualize the Intersection Scene

For each maneuver type, CDATS provides videos embedded with text, audio narration and driving simulation scenes to highlight hazards and practice real-time hazard perception. Overhead camera angles are utilized to overcome typical driver field-of-view (FOV) limitations and improved visualization of the traffic scene, especially for hazards involving visual FOV obstructions (e.g., large truck obstructing the view of a pedestrian).

As shown in **Figure 2,** for an unprotected left-turn maneuver, a driving simulation video starts from a typical driver FOV. As the video progresses, it pauses at a pre-maneuver zone and asks, “Where are the potential hazards prior to the intersection?” (**Figure 2a**) The camera angle then shifts to an overhead view and all potential hazards are explicitly highlighted (verbally and graphically) in a serial fashion (**Figure 2b**). The camera angle then returns and the drive proceeds to the actual intersection where the video pauses again and asks, “Where are the potential hazards during and immediately after your left turn?” (**Figure 2c**) As before, the camera angle shifts to an overhead view and all potential maneuver and post-maneuver hazards are highlighted (**Figure 2d**). The camera angle returns and the simulation continues. The entire intersection scene is then repeated in the normal driver FOV to allow students to practice detecting and anticipating hazards in a more realistic driver FOV and speed.

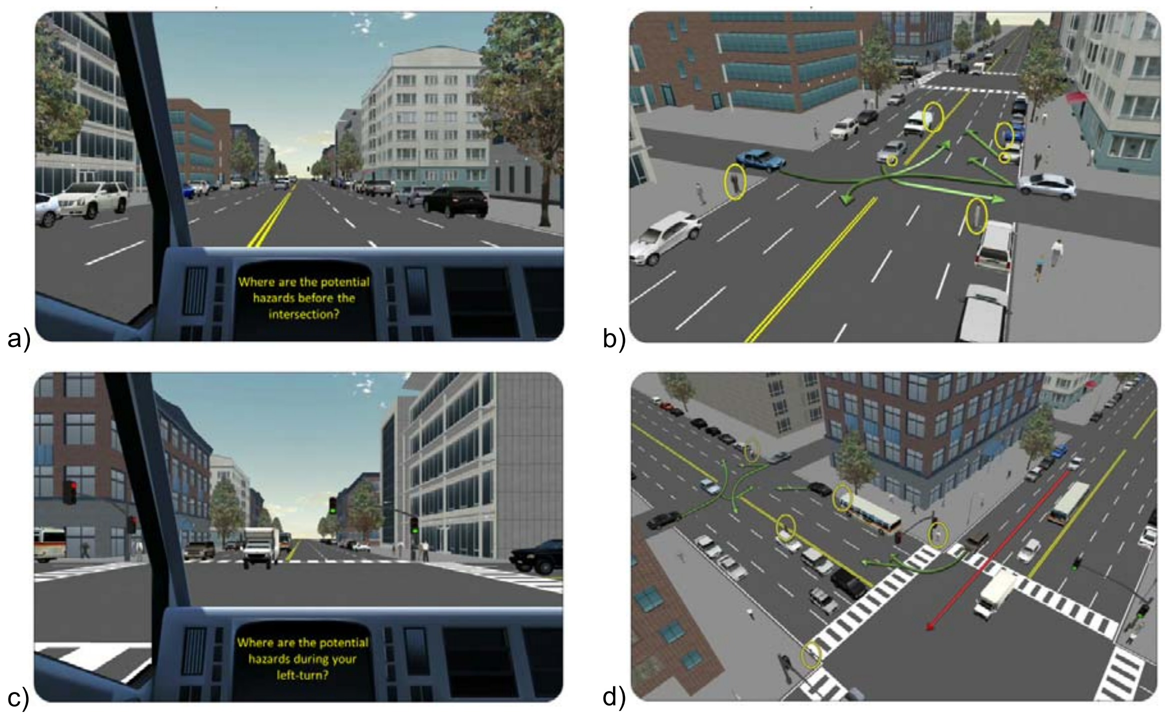
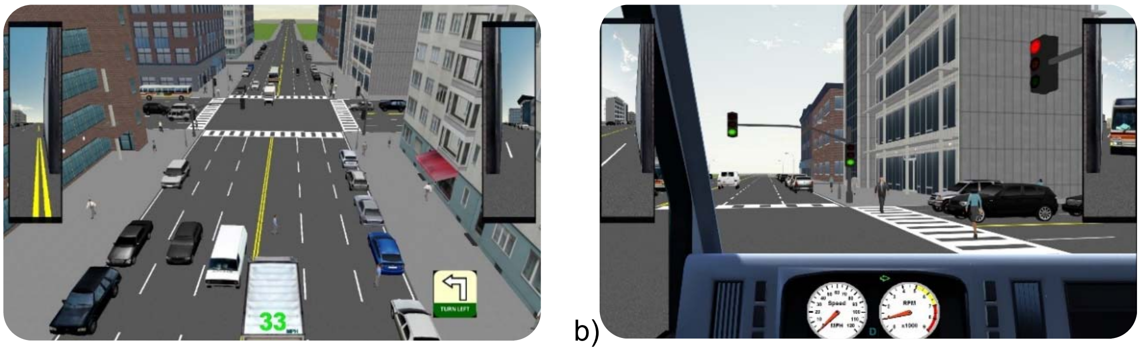


Figure 2. CDATS training video scenes using embedded simulation for an unprotected left-turn intersection maneuver. Scenes pause (a, c) and camera angles shift to highlight hazards prior to intersection (b) and during/after the left-turn maneuver (d).

Reinforcement thru Driving Simulation

Video lessons are reinforced using the same driving scenarios presented on a single-screen, low-fidelity, desktop simulator. Potential hazards (formally static for highlighting purposes) are now activated to cross the driver’s path, allowing students to practice pre-event behaviors (e.g., speed reduction, brake covering, delayed execution). In these scenarios, the rare occurring hazards are just as likely, if not more, to be presented to drivers. Thus, potentially increasing the expectation of factor of specific hazards. Additional simulation drives where an elevated, driver FOV are also provided to overcome limited FOVs in the simulator (**Figure 3**). Such driving configurations may provide useful training methods for low-fidelity simulation training where situational awareness and mental constructs of traffic environments are emphasized over vehicle control.

Although previous studies used birds-eye-view images of the roadway (Pradhan, Pollatsek, Knodler, & Fisher, 2009), realtime traffic videos (McKenna & Crick, 1997; Underwood, 2007), and driving simulation scenarios requiring collision avoidance (Allen, Park, & Cook, 2008; Allen, Park, Cook, & Fiorentino, 2007), CDATS is one of the few programs attempting to combine the advantages of the aforementioned programs together; although see McDonald, Goodwin, Pradhan, Romoser and Williams (2015) for review. Our method of using simulation footage lends itself to more efficient curriculum development, scene control, and design flexibility.



a) b)

Figure 3. CDATS driving simulation scenes: (a) elevated driver FOV, white truck at center bottom is driver's vehicle with speedometer and turn instructions displayed, (b) normal driver FOV as driver's vehicle is making a right-turn.

CDATS Training Prototype & Curriculum

To meet the traffic safety and training needs of commercial motor carriers, developed was a prototype for the Commercial Driver Assessment & Training System (CDATS): a cloud-based, CMV driver training system that uses multimedia instruction and innovative driving simulation techniques to supplement traditional, driver job training and increases the HD skills of CMV drivers. By focusing on perceptual- and cognitive-based, HD skills for everyday driving environments: 1) the core curriculum addresses the main contributor to crashes and is thus applicable to a broad range of CMV operations and drivers, and 2) a simulator station could use inexpensive, off-the-shelf, driver controls (< $400) or potentially no driver controls at all. By integrating low-cost, driving simulation technology with a cloud-based data solution, simulation-based training can be deployed in a cost-effective manner and used anywhere there is internet service (**Figure 4**). Training curriculum materials and driver assessment/training data (e.g., survey and HD performance) are now accessible online for management, tracking,

Figure 1. CDATS hardware example.

The CDATS training curriculum (**Table 1**) comprised of a series of videos for each intersection maneuver type. Driving simulator training used an elevated FOV configuration and then normal FOV training drives. Each of the training drives exposed drivers to the three intersection maneuver types with hazards activated to collide or near collide into the driver's vehicle if no action was taken. Total training time: 31 min.

Table 1. CDATS Training Curriculum

Training Items	Time (min)
Training Videos	
CDATS Introduction, Motivation, & Goals	4
Unprotected Left-Turn Intersections	4
Unprotected Right-Turn Intersections	4
Unprotected Straight-Thru Intersections	4
Driving Simulator Training	
Elevated FOV Driving Simulation	5
Normal FOV Driving Simulation 1	5
Normal FOV Driving Simulation 2	5

Specific Aim 3: Evaluation of CDATS

To assess the HD training potential of CDATS, a pilot-training study was performed, $N = 16$. HD performance (HD task accuracy, % correct) was measured using a wide-FOV driving simulator and HD task composed of potential hazards (e.g., vehicle, pedestrian, and visually hidden hazards) during unprotected, intersection maneuvers (left-turn, right-turn, and straight-thru). A potential hazard was defined as anything or situation that may result in a collision; requiring an evasive action such as slowing down, braking, or steering. The HD task was presented to participants before random assignment to either the CDATS training or control group (pre-test) and 1-week later (post-test). Control group participants were provided a series of hazard recognition and response scenarios utilized in prior novice driver training studies (Allen, Park, Terrace, & Grant, 2011).

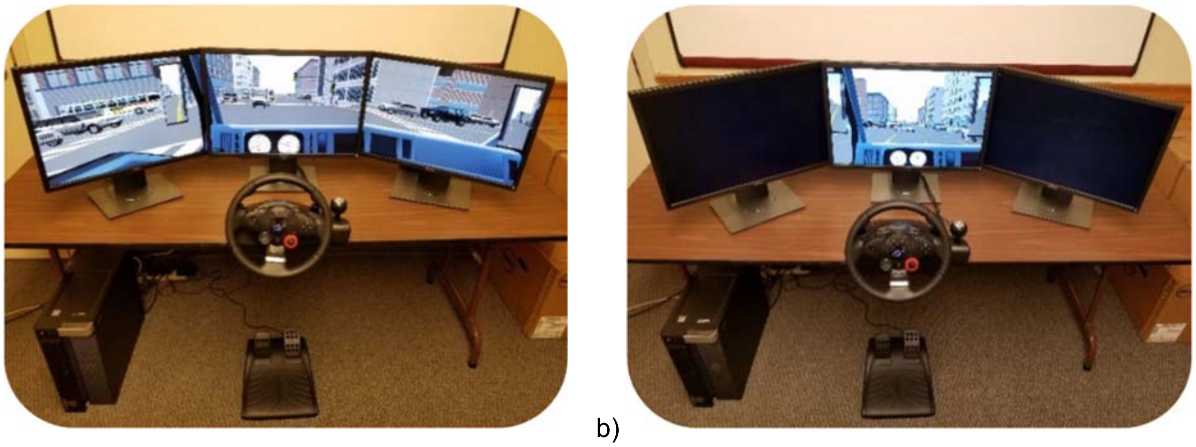
Methods

Participants

Sixteen subjects (15 male, aged 24-57 yr.,) participated in this study. All subjects were experienced, short-haul CMV drivers (e.g., short-haul, package delivery) with an average of 15 yr. of work experience (range: 3 to 33 yr., *SD* = 11 yr.) with an average of 73 mi driven per shift (*MDN* = 55 mi, *SD* = 60 mi). Recruited from advertisements (internet and flyers), subjects were compensated $75 per session completed; 2 sessions total.

Driving Simulator

The driving simulator system (**Figure 5**) was generated by STISIM Drive® (Build 3.14.04) and processed by a Dell Precision Tower 5810. The Logitech Driving Force GT steering wheel and pedals (900° rotation; automatic transmission) was used for driver controls and recording the HD task button responses. For the pre/post-test drives, a 150° horizontal FOV of the driving scene was provided using three monitors (22” diagonal, 1680 x 1050 pixels). For the CDATS training and control group drives, a 60° horizontal FOV was provided using only the center monitor. The elevated FOV setting was established by situating the driver’s eye/camera position in the virtual scene, relative to vehicle model center: 57 ft vertical, -74 ft longitudinal, and -20° downward pitch.



a) b)

Figure 5. Driving simulator configurations for pre/post-tests (a) and CDATS/control group training (b).

HD Task at Pre/Post-Test Drives

Nine intersections (3 left-turns, 3 right-turns, 3 straight-thru) spaced ~2,000 ft apart were randomly presented for a total driving distance of 18,900 ft (3.6 miles); drive time: ~8 min. Each intersection scene had the following design: ~1,100 ft in driving length, 6 lanes across (12 ft each), double-yellow centerline, unprotected green signal lights, intersection crosswalks, 2-lane side streets ~200 ft before/after and left/right of the intersection, and urban style building models. Minimal ambient, oncoming traffic was provided between intersections.

All hazards were static in scene position. Vehicle hazards involved waiting passenger-type vehicles signaling to cross or change lanes in front of the driver. Pedestrian hazards involved pedestrians standing 10 ft off-sidewalk, facing road-center or on-sidewalk at one of the intersection crosswalk corners. Hidden hazards involved a large vehicle (e.g., delivery truck or bus) obstructing the view of crossing traffic or pedestrians.

Pedestrian or vehicle hazards were randomly positioned singularly at sections: (i) pre-maneuver (200 ft zone prior to intersection), (ii) immediate area of the intersection maneuver, or (iii) post-maneuver (200 ft zone after intersection). A hidden hazard was positioned once during the pre-maneuver or maneuver sections. A third of the sections did not contain any hazards. Therefore, a single test drive resulted in 12 visible hazards (6 pedestrians, 6 vehicles) and 6 hidden hazards (half large truck, half transit bus). Half the hazards were positioned on either the right or left side of the driver's FOV. For the post-test drive, building models were re-arranged while maintaining the same road design and a counterbalanced version of the intersection types and hazards were presented.

HD Task Procedure

When participants detected a hazard, they were instructed to press the HD button located on the steering wheel as quickly as possible. When pressed, the HD button paused and blacked-out the simulation scene. Participants then verbalized what and where the potential hazard was. When finished, participants would re-press the button to un-pause and continue the test drive. Performance feedback was only provided at study completion. Participants' vehicle speed maxed at 40 mph to minimize hazard approach speed differences. Additional participant instructions included: (i) drive as if making normal deliveries in your work vehicle, (ii) maintain 40 mph when safe to do so, (iii) pay attention to any turn instructions, (iv) there is no right or wrong way to drive and you will not be judged on how you drive, (v) it is ok if you do not detect any hazards as not every section will contain a hazard, and (vi) point out more than one hazard during a pause if noticed.

Control Group Scenarios

For the control group, 5 driving scenarios (total drive time: 30 min) were selected to improve vehicle handling skills and expose participants to novice driver hazard detection/response drives (Allen et al., 2011). The first scenario was a raceway drive where the goal was to pass as many race cars as possible. Remaining four scenarios involved a variety of driving speed and building environments (e.g., residential, urban, and rural), where pedestrian/vehicle hazards could potentially collide with the driver if no evasive action was taken.

Additional Test Materials

Questionnaires were developed to collect basic demographic information, health status, driving history (e.g., professional experience, average mileage/shift, past crash/citation within 2 yrs.), and system usability. The Simulator Sickness Questionnaire (SSQ) was used to measure any simulator sickness symptomology (Kennedy, Lane, Berbaum, & Lilienthal, 1993). SSQ and usability data not reported here for brevity.

Procedure

Data was collected using two session visits. At session 1, participants began by completing the informed consent, questionnaires, and SSQ-baseline. Participants were introduced to the driving simulator and HD task in a practice drive. When comfortable, participants were given the pre-test drive, followed by SSQ and usability surveys. The training group was then provided the CDATS training curriculum. The control group was provided the control group scenarios. Following completion, SSQ was collected and participants were excused with compensation ($75). Total session 1 time: 1.5 hrs.

Participants returned 1-week later for session 2. Health status changes were noted and SSQ-baseline was collected. The practice and post-test drive were then provided, followed by SSQ and survey. Participants were then debriefed. For the CDATS group, an exit interview was conducted. For the control group, the option for experiencing the CDATS training materials was provided. Participants were then compensated ($75), and excused. Total session 2 time: 1 hr.

Specific Aim 4: Data Reduction and Analysis

Hazard Detection Task Accuracy

A 2 (test: pre, post) x 2 (group: training, control) x 3 (hazard type: vehicle, pedestrian, hidden) x 3 (intersection maneuver: left, right, straight) mixed of covariance was performed for HD task accuracy (% correct), $N = 16$, $\alpha = .05$. The covariate factor was driving experience (yrs. driving professionally). Means reported with ± standard error.

A significant hazard type x intersection maneuver interaction, $F(4,52) = 6.39$, $p < .001$, $\eta^2_p = .329$, suggested that participants missed hazards differently depending on the types of maneuvers performed at an intersection. For each intersection maneuver, simple main effects were assessed followed by Bonferroni pairwise comparisons. Main effects for intersection type, $F(2,28) = 7.62$, $p = .002$, $\eta^2_p = .352$, and hazard type, $F(2,26) = 29.30$, $p < .001$, $\eta^2_p = .693$, were also found.

As shown in **Figure 6**, at intersections where drivers made unprotected left-turns, $F(2,30) = 69.65$, $p < .001$, mean HD task accuracy for vehicle hazards were high (92 ± 4%), but not statistically different for pedestrian hazards (73 ± 7%), $p = .086$. Mean accuracy for hidden hazards during left-turns (9 ± 6%) was very low compared to pedestrians ($p < .001$) and vehicles ($p < .001$). At intersections where drivers made unprotected right-turns, $F(2,30) = 31.44$, $p <$

.001, mean accuracy for vehicle hazards (78 ± 7%) was higher compared to pedestrian hazards (52 ± 4%), $p = .005$. Mean accuracy for hidden hazards (20 ± 5%) was the lowest compared to vehicles ($p < .001$) and pedestrian hazards ($p = .002$). At intersections where drivers continued straight-thru, $F(2,30) = 57.53$, $p < .001$, mean accuracy was higher for vehicle hazards (92 ± 4%) compared to pedestrian hazards (30 ± 6%), $p < .001$, and hidden hazards (19 ± 7%), $p < .001$. No difference found between pedestrians and hidden hazards ($p = .609$).

A significant text x group interaction was found, F(1,13) = 7.97, p = .014, η2p = .380. T-tests confirmed no difference in mean HD task accuracy between the training (46 ± 5%) and control group (46 ± 5%) at pre-test (p = .946). However, at post-test, the training group scored on average better (65 ± 4%) than the control group (49 ± 4%), t(14) = 2.71, p = .017 (**Figure 7**). The covariate, driving experience, was not related to HD task accuracy (p = .985, F < 1.0).

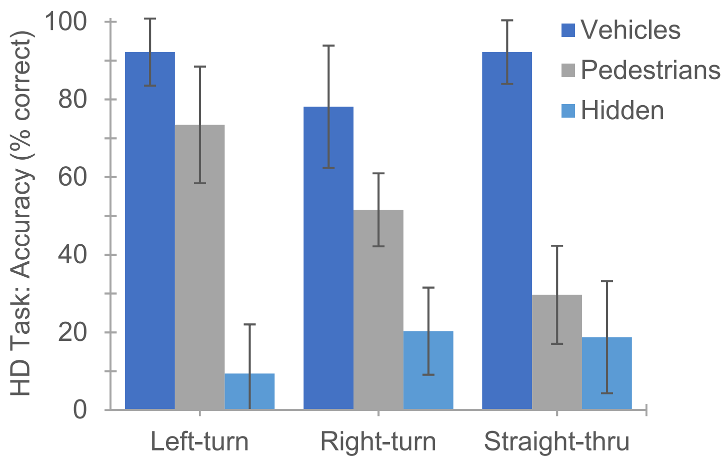


Figure 6. Mean HD task accuracy for hazard type by intersection maneuvers with 95% CIs.

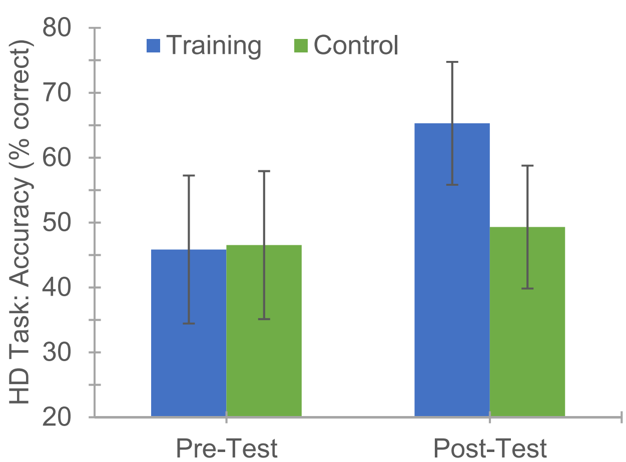


Figure 7. Mean HD task accuracy at pre/post-tests by group with 95% CIs.

Discussion

To assess the HD training potential of CDATS, a pilot-training study was performed using a sample of experienced, short-haul CMV drivers, $N = 16$. HD performance (HD task accuracy, % correct) was measured using a wide-FOV driving simulator and HD task composed of potential hazards (e.g., vehicle, pedestrian, and visually hidden hazards) during unprotected, intersection maneuvers (left-turn, right-turn, and straight-thru). The HD task was presented to participants before random assignment to either the CDATS training or control group (pre-test) and 1-week later (post-test).

In accordance to prior studies (Horswill et al., 2013), experienced, professional drivers can also exhibit poor HD—particularly for visually hidden and visible pedestrian hazards—and may benefit from HD training. CMV drivers had the least difficulty detecting the vehicle hazards that were visible and signaling their intentions. Relative to pedestrian hazards, vehicles were larger in size and had turn signal light motions to aid attentional capture. This may have contributed significantly to higher HD accuracy. Vehicle collisions may also represent more of a perceived threat to the driver's personal safety compared to pedestrian collisions. Thus, drivers were perhaps prioritizing the detection of vehicles over pedestrian or hidden hazards. CMV drivers had the most difficulty detecting the hidden potential hazards, regardless of the intersection maneuver. Although the obstructing objects (e.g., bus) were larger in size than the vehicle hazards, drivers did not view them as a visibility threat, let alone expect pedestrians or vehicles to be located behind them. Visibility-based hazards present a clear challenge for even experienced, professional drivers.

CMV drivers detected visible pedestrian hazards differently depending on the intersection maneuver. At unprotected left-turns, pedestrians were detected as well as vehicle hazards. At unprotected right-turns, pedestrians were detected less but better than hidden hazards. This difference between left- and right-turns may have been due to vehicle positioning differences while waiting to execute the turns. Drivers during unprotected left-turns could be positioned more center of the intersection, providing a better visual FOV for hazard scanning to the upcoming left roadway. During right-turns, the driver's vehicle usually remains short of the intersection crosswalk, limiting the FOV to the right. At unprotected straight-thru intersections, pedestrians were detected no better than hidden hazards. The drop in HD accuracy for pedestrians at the straight-thru intersections was potentially due to the timing demands of the maneuver. At turning intersections, drivers did not necessarily have the right-of-way and had time to wait and scan the environment, prior to turning. At straight-thru intersections where drivers had the green light and right-of-way, drivers had less time. Future studies imposing time restraints on intersection turning maneuvers may reveal pedestrian HD deficits like straight-thru maneuvers. It is also possible that drivers during the straight-thru intersections did not expect pedestrians to cross—visible or otherwise. Interestingly, they did not assume the same from other vehicle drivers, as evident in their high detection of vehicle hazards.

The CDATS program showed potential to improve HD skills for CMV drivers during unprotected intersection maneuvers. At pre-test, no group differences were observed for HD task accuracy. At post-test, CDATS trained drivers improved their HD task accuracy compared to the control. Group differences at post-test could not be attributed to one group being exposed to more driving simulator scenarios. Control group drivers did not appear to benefit from novice driver oriented scenarios. This suggests that CMV drivers may benefit more from cognitive-based training programs for HD.

Study Limitations

Several limitations are present for the current study. First, the CDATS program was designed specific to short-haul, CMV drivers. Different HD challenges may appear for long-haul, CMV drivers. The sample size itself was also relatively small, warranting a larger study.

Second, it remains to be seen if CDATS training translates to reductions in real world crash risks and rates. While correlations have been found with HD skills and crash rates, it is unclear if the current curriculum is expansive enough to make a significant impact. Therefore, an expansion of the curriculum is warranted.

Finally, HD performance during simulator tests indicated that CDATS participants did not reach ceiling. It is possible that the driving simulator HD task was too difficult or that improvements in CDATS training is warranted. The training videos were passive in nature and did not provide any performance feedback. Therefore, it is unclear if lessons were fully understood, or practiced enough to translate into better simulator performance. Future CDATS designs will require a method of assessing the training process of drivers.

Future Work

Future work for CDATS includes the development of an expanded HD training curriculum, which includes:

- Left- and right-turns at unprotected, t-intersections. Left-turns at t-intersections where traffic approaches from left/right can be a difficult driver maneuver and poses a challenge for simulators where horizontal FOV is limited. CDATS techniques using elevated FOV simulations may overcome these challenges.
- Protected, intersection maneuvers – right, left, straight. This includes development of intersections with pedestrian walk/don't walk signals, dedicated turn-arrows and lanes. In Phase I, intersections with timing constraints and assumptions of right-of-way may challenge CMV drivers during HD.
- Pedestrian types – varying pedestrian sizes (e.g., adult vs. child) and cueing (e.g., walk-stop, head turning, jogging). In Phase I, vehicles had a possible attentional capture advantage due to model size and blinking turn signal motions. Pedestrians with more realistic animations may reveal different results.
- Vehicle types – bicycles and motorcycles. Bicycles provide additional hazard complexity to a scene due to their road sharing depending on roadway design and presence of bike lanes. Motorcycles present a difficult HD challenge due their smaller size and ability to be visually hidden.
- Visually hidden hazards based on roadway obstructions (e.g., hedge) or design (e.g., curvature). In Phase I, visibility-based hazards presented the most difficulty for CMV drivers and these hazards may be equally challenging.

In addition, the future work includes the development of an interactive video lesson (IVL) application which pauses videos and has trainees select hazardous areas of interest (AOIs) with immediate performance feedback. This IVL application may provide the most dramatic improvement in HD training because it provides: 1) an engaging, interactive means of detecting hazards, 2) ability to use simulation-based videos; taking advantage of wide or alternative field-of-views (FOVs), 3) ability to use digital camera-based videos; taking advantage of image realism, 4) immediate performance feedback provides trainees with personal skill insight and allows for deliberative, self-paced practice, 5) removal of performance feedback transforms application into an assessment routine, 6) customizable curriculum for more specific CMV operations or environments, and 7) potentially sufficient HD skills training for experienced drivers, negating the need for driver control hardware; allowing training to occur anywhere.

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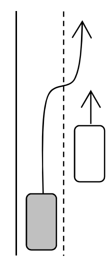
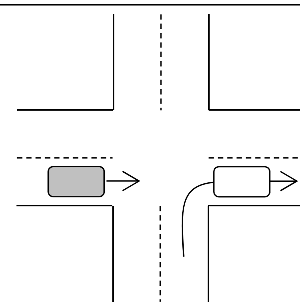
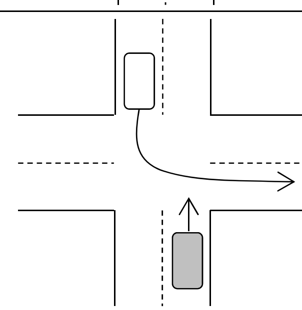
APPENIDIX A: Literature Review

1. Hanowski, R.J., Hickman, J.S., Wierwille, W.W., Keisler, A. (2007). A descriptive analysis of light vehicle – heavy vehicle interactions using in situ driving data. *Accident Analysis and Prevention, 39*(1), 169-179.

Results below focus on local/short-haul (L/SH) operations using naturalistic driving data collection (limited to interactions with passenger vehicles, which was 56.6% of the total incidents). The L/SH operations focused on two participating companies that delivered snack foods and beverages. There were a total of 142 critical incidents involving an L/SH truck in the study. The most common incident types in these 142 critical incidents were: lane change without sufficient gap (21.1%), roadway entrance without sufficient clearance (18.3%), and left turn without clearance (14.8%).

Lane Change Without Sufficient Gap 21%	A driver enters an adjacent lane without allowing adequate space between the driver's vehicle and the vehicle ahead/behind it. Are they checking or mis-reading or workload?	
Roadway Entrance Without Clearance 18%	A driver turns onto a roadway without adequate clearance from through traffic.	
Left Turn Without Clearance 15%	A driver turns left without adequate clearance from either oncoming through traffic or cross traffic from the left. The driver crosses another driver's path while entering an intersecting roadway.	

2. Massie, D.L., Blower, D., & Campbell, K.L. (1997). *Short-Haul Trucks and Driver Fatigue*. Washington, DC: The Office of Motor Carriers Federal Highway Administration.

This study used truck crash statistics derived from the 1991-1993 Trucks Involved in Fatal Accidents file and, to a lesser extent, 1995 SafetyNet data to determine the prevalence of fatigue in class 3-6 single-unit straight trucks in local service. The prevalence of truck driver fatigue coded in fatal involvements was found to be 1.9% and the prevalence in personal injury or towaway involvements was 1.3%. The majority of these fatigue-related involvements were single-vehicle crashes, with 71% of the fatal involvements and 72% of the less severe involvements. Rollover and fixed object collisions were especially common types of fatigue-related fatal involvements. Distributions of fatigue-related involvements over the hours of the day showed a sharp peak from 4-7 .A.M. for fatal involvements and a broader peak from 3-7 A.M. for less severe involvements.

3. National Highway Traffic Safety Administration. (2013). *Traffic Safety facts 2011: Single-Unit Straight Trucks in Traffic Crashes*. Washington, DC. National Highway Traffic safety Administration.

Data from the Fatality Analysis Reporting System (FARS) and General Estimates System (GES) show that, in 2011, about 3 percent of fatal crashes, 1.7 percent of injury crashes, and 2 percent of property-damage-only (PDO) crashes involved single-unit trucks (SUTs). Crashes involving SUTs killed 1,064 people and injured about 38,000 people. Additionally, about 87,000 SUTs were involved in crashes that resulted in major property damage. Figure 1 displays a comparison between the first harmful event and most harmful event for fatal, injury, and PDO SUT crashes. These results largely support the MCMIS analysis I created (i.e., that most crashes involving a 2-axle, 6 tire truck or and parcel delivery trucks occur while the vehicle is in transport). Figure 2 displays the manner of collision in fatal, injury, and PDO SUT crashes. These results largely support the common Incident Types in Hanowski et al. (2007). Most of the SUT crashes in Figure 2 were angle (i.e., T-bone) and front-to year (i.e., SUT rear-end striking). A large percentage of the PDO crashes were sideswipe, same direction.

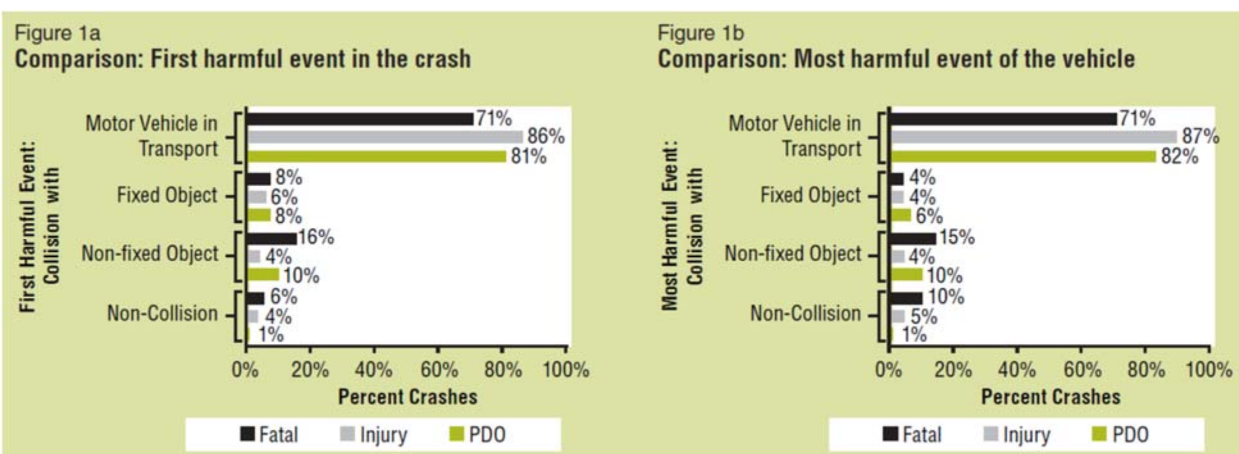


Figure 1. Comparison between first harmful event and most harmful event for fatal, injury, and PDO crashes.

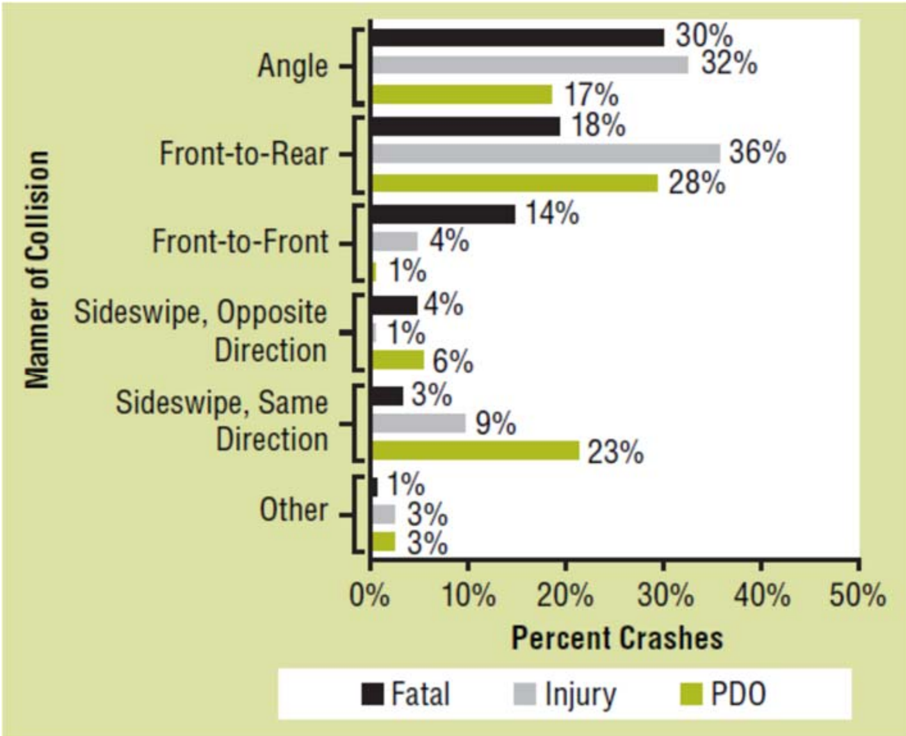


Figure 2. Comparison of manners of collision in fatal, injury, and PDO crashes.

4. Hanowski, R.J., Wierwille, W.W., & Dingus, T.A., (2001). An on-road study to investigate fatigue in local/short-haul trucking. *Accident Analysis and Prevention, 35*, 153-160.

Two L/SH trucking companies and 42 L/SH drivers participated in this research. The analyses focused on determining if fatigue is an issue in L/SH operations. Of primary interest were critical incidents where L/SH drivers were judged to be at fault. The results indicated that PERCLOS (percent eye closure) values were significantly higher (by tenfold) in the L/SH at-fault incidents compared to the incidents where the L/SH driver was not at-fault. The authors speculated that drivers' off-hours behavior likely played a significant role in the fatigue experienced on the job.

5. National Transportation Safety Board, (2013). *Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths.* Safety Study NTSB/SS-13/01. Washington, DC.

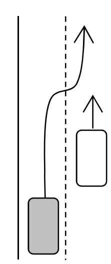
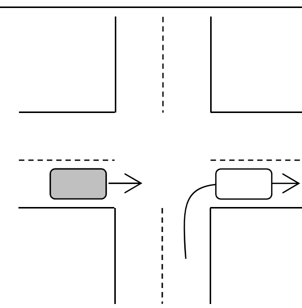
This study used a variety of data sources. Crash Outcome Data Evaluation System (CODES) data, which links hospital discharge records with police accident reports, were obtained from five participating states (Delaware, Maryland, Minnesota, Nebraska, and Utah) and served as the primary source of data for injury severity and hospitalizations in relation to truck and accident characteristics. Additional databases used included Trucks in Fatal Accidents (TIFA) and the Fatality Analysis Reporting System (FARS) (fatal crashes); the National Automotive Sampling System (NASS)/General Estimates System (GES) (national estimates of non-fatal injuries); and the Large Truck Crash Causation Study (LTCCS) (truck crash investigations with details not available from the other sources).

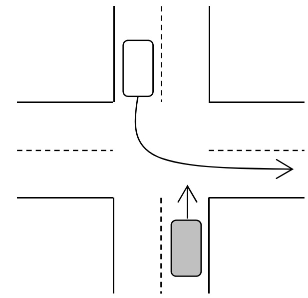
The study found that the adverse effects of SUT crashes have been underestimated in the past because these trucks are frequently misclassified and; thus, undercounted in federal and state databases (approximately 20 percent in the case of fatalities). There are substantial societal impacts resulting from single-unit truck crashes, including deaths, non-fatal injuries, hospitalizations, and hospital costs. Areas identified for safety improvements include the need to (1) enhance the ability of drivers of single-unit trucks to detect vulnerable road users such as pedestrians and cyclists, (2) prevent passenger vehicles from under-riding the rears and sides of single-unit trucks, (3) improve conspicuity of single-unit trucks, (4) improve federal and state databases on large truck crashes, (5) continue the functions of databases vital for accurate fatality data or that link hospital data with police reports, (6) examine the frequency and consequences of single-unit truck drivers operating with an invalid license, and (7) research the potential benefits of expanding the commercial driver's licensure requirement to lower weight classes.

Hazard Perception Scenarios

The crash and hazard perception literature and MCMIS database analysis informed the scenarios below. Materialized hazards are those that require an immediate evasive action, or obvious traffic sign indicating a hazard or reduction in speed. Potential hazards are situations that may actually turn into a hazard.

Materialized Scenarios

Lane Change Without Sufficient Gap	A driver enters an adjacent lane without allowing adequate space between the driver's vehicle and the vehicle ahead/behind it. Why? Is sim training with mirrors good for improving perceptual cues?	
Roadway Entrance Without Clearance	A driver turns onto a roadway without adequate clearance from through traffic. Why? Miss timing of CT, or inattention blindness or obstructed view more likely? Car doesn't have enough accel, maybe a vehicle load issue?	

Left Turn Without Clearance	A driver turns left without adequate clearance from either oncoming through traffic or cross traffic from the left. The driver crosses another driver's path while entering an intersecting roadway. Obstructed view most likely	

- Parked cars on the driver's lane and another car approaching from ahead in the opposite lane (the car is the signal to slow down)
- Car approaches a speed limit sign that indicates a reduction in speed (the sign is the signal to slow down).
- Traffic light ahead turns yellow (the yellow light is a signal to slow down)

Potential Hazards

- A row (or several) of parked cars and a pedestrian emerges from between the cars. The parked cars should be a cue to slow down as vision is obscured to the sidewalk.
- A child's bike on the sidewalk or lawn and no child in sight, that would be a cue for the driver that a child may be somewhere in the area and thus, should slow down. This is a similar cue as the parked cars.
- Slower cyclist ahead serves as a precursor for slower traffic ahead.
- Trees or bushes block drivers view on a curve, this could obscure a side road with a car trying to turn.