

Field Demonstration of Heavy Vehicle Camera/ Video Imaging Systems

2011-01-2245

Published
09/13/2011

Gregory Fitch, Myra Blanco, Richard Hanowski and Matthew Camden
Virginia Tech Transportation Institute

doi:10.4271/2011-01-2245

ABSTRACT

To help drivers monitor the road and to reduce blind spots, Camera/Video Imaging Systems (C/VISs) display live video from cameras mounted on the truck's exterior to drivers using displays inside the truck cabin. This study investigated drivers' performance with C/VISs in a real-world trucking operation. Twelve commercial drivers' performance with and without a C/VIS was continuously recorded while they each drove for four months. Half of the drivers used a commercially available C/VIS that had a side-view camera on each fender. The other drivers used an advanced C/VIS (A-C/VIS) that had side-view cameras, a rear-view camera, and night-vision capabilities. This paper presents the study's final results and expands on the preliminary results that were previously reported. Detailed analyses of drivers' involvement in Safety-Critical Events (SCEs), their lane change performance, and their opinions of the C/VISs are presented. Overall, it was found that when a C/VIS was provided: 1) drivers' involvement in safety-critical events (SCEs) did not change, 2) the probability that drivers looked forward did not change, 3) the clearance to an adjacent vehicle when changing lanes did not change, 4) drivers were more likely to use the C/VIS at night and when making right lane changes, and 5) drivers indicated that the C/VISs helped them become aware of surrounding objects and merge into traffic. In terms of disbenefits, some drivers indicated that glare from the commercially available C/VIS monitors, as positioned to specifications, could be uncomfortable at night. The A-C/VIS's advanced features were highly rated by drivers. The rear-view camera was also used more than the left or right fender cameras. In summary, it was found that C/VISs are able to assist CMV drivers in their daily driving task without deteriorating their driving performance.

INTRODUCTION

Large blind spots exist along the sides, rear, and front of Commercial Motor Vehicles (CMV) ([Figure 1](#)) [1]. Camera/Video Imaging Systems (C/VISs) use cameras mounted on the truck's fenders and trailer to provide drivers with a view of the area around the CMV. C/VISs provide a countermeasure to blind-spot related crashes by allowing drivers to see objects not ordinarily visible by a typical mirror configuration. C/VISs are expected to help reduce the number of crashes resulting from improper CMV lane changes/merges, turning maneuvers, and backing maneuvers, which account for 6.3 percent of all truck crashes (20,311 crashes), according to an analysis of the 2009 National Automotive Sampling System/General Estimates System (GES) data [2]. This analysis also found that these types of crashes account for 2.0 percent of fatal and incapacitating truck crashes (165 crashes), 6.1 percent of injurious truck crashes (1,426 crashes), and 7.4 percent of non-injurious truck crashes (18,719) [2]. Furthermore, C/VISs may reduce the number of rear-end crashes if they allow drivers to quickly determine the location of adjacent vehicles and spend less time looking away from the forward roadway.

The National Highway and Traffic Safety Administration (NHTSA) and the Federal Motor Carrier Safety Administration (FMCSA) have collaboratively funded research related to C/VISs. Previous C/VIS research under the Indirect Visibility Program consisted of the following: 1) developing a static testing method for assessing the quality of indirect visibility on CMVs [3], 2) developing a performance specification for daytime C/VISs on CMVs [4], and 3) developing an enhanced C/VIS (E-C/VIS) to provide all-around visibility to drivers during nighttime and inclement weather conditions [5]. Based on the promising results from these studies, NHTSA and FMCSA funded the Virginia Tech Transportation Institute (VTTI) to evaluate driver performance in a revenue-producing environment with one of

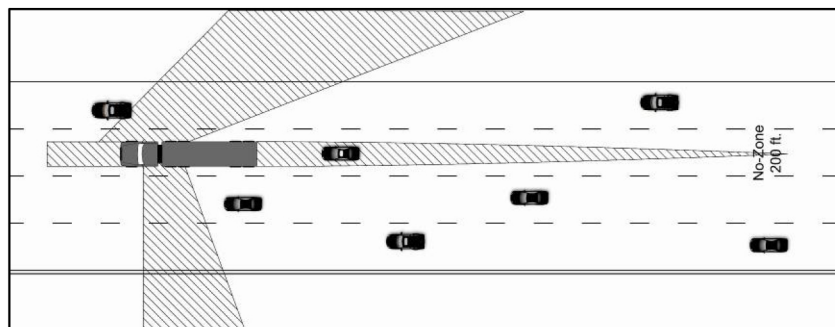


Figure 1. CMV Blind Spots Shown by Hatched Areas. Adapted from [3].

two C/VISs: 1) an Advanced C/VIS (A-C/VIS) that possessed the E-C/VIS's functionality, while being suitably rugged for commercial trucking operations, and 2) a commercially-available C/VIS. Driver performance with these C/VISs was investigated through a Technology Field demonstration (TFD), which consisted of installing data acquisition systems on a number of trucks and continuously recording video and parametric data as drivers operated the trucks with and without a C/VIS [6]. This paper presents the study's final results and expands on the preliminary results that were reported [7]. Detailed analyses of drivers' involvement in Safety-Critical Events (SCEs), their lane change performance, and their opinions of the C/VISs are presented.

METHOD

PARTICIPANTS

Twelve Commercial Driver's License (CDL)-qualified drivers participated in this study. All drivers were employees of Schneider National, Inc and worked at the Winchester, Virginia operation. This operation ran a daily-delivery service where each participant drove the same route each day. The majority of the participants' driving was performed at night. Their shifts began as early as 5:00 PM and as late as 1:00 AM. Participants' shifts ended as early as 3:30 AM and as late as 11:00 AM. All participants traveled alone for the duration of their shifts. The drivers' average age was 39 years old (Min = 26 years old, Max = 53 years old). All participants had a minimum visual acuity of 20/40. Eleven drivers completed all four months of the study, while one driver completed three months of the study before he quit his employment.

TEST VEHICLES

Schneider National, Inc provided six Freightliner C120 Century tractors from their Winchester, Virginia operation for use in the TFD. The tractors were attached to 48-foot long trailers, which were the longest trailers available at this operation. In order to minimize interference with the data collection system, the study required that the tractors remained permanently coupled with the trailers. This is

atypical in the trucking industry. During the fleet company recruitment process Schneider National, Inc was the only company who agreed to operate under this constraint. The Winchester, Virginia operation was selected because it was the most cost-effective to travel to with respect to collecting data throughout the TFD.

CAMERA/VIDEO IMAGING SYSTEMS

Two C/VISs were used in the TFD. The first was a commercially available C/VIS, while the second system was the A-C/VIS developed by VTTI. Both are briefly described below, while additional information is presented in [6].

Commercially Available C/VIS

The selected commercially available C/VIS was a cab-only solution, where one camera was mounted on the left fender pointing back along the left side of the trailer (Figure 2a), and another camera was mounted on the right fender pointing back along the right side of the trailer (Figure 2b). Each camera's Field-of-View (FOV) was 88 degrees, which provided wide coverage but also increased image distortion. Two monitors were mounted on the dash inside the truck cabin, one on the left side of the steering wheel, and one on the right side of the steering wheel (Figure 2c). The commercial C/VIS settings were selected through an on-screen menu and included the ability to adjust the brightness, contrast, tint, and color of the video image. The views provided by the two cameras are shown in Figure 3 by the shaded areas.

A-C/VIS

The A-C/VIS was a road-worthy version of an earlier E-C/VIS prototype that was designed and tested at VTTI [5]. It had three cameras mounted on the CMV to relay video to drivers inside the cab using three monitors. One camera was mounted on the left fender and was positioned to point back along the left side of the truck (Figure 4). Another camera was mounted on the right fender and was positioned to point back along the right side of the truck. A third camera was mounted on top of the back side of the trailer and was positioned to point down behind the trailer. The views



Figure 2. Commercial C/VIS Camera Placement

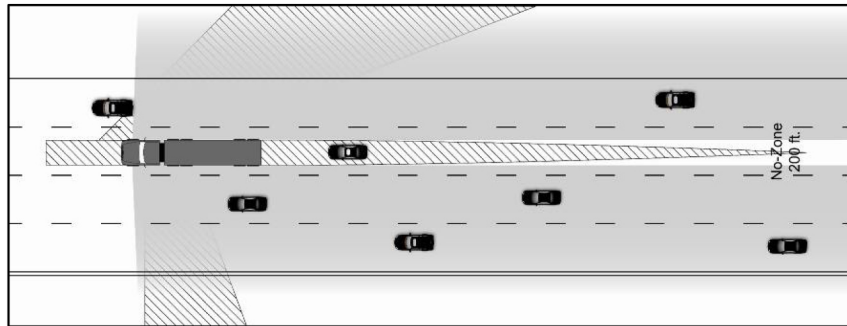


Figure 3. Coverage Provided by the Commercial C/VIS (Shown by Grey Shading)



Figure 4. A-C/VIS Cameras Mounted on Truck Exterior

provided by the three cameras are shown in [Figure 5](#) by the shaded areas.

To provide drivers with a better view at night, infrared illuminators were mounted along the side and rear of the CMV. The cameras were sensitive to infrared light, allowing drivers to perceive objects that are typically invisible at night. Visible light illuminators were not used because testing revealed that the infrared illuminators were preferred by drivers and produced no glare to passing traffic [5].

The three monitors were mounted inside the cab along the top of the windshield ([Figure 6](#)). The monitors were positioned so that they did not block the drivers' view of the roadway, or create a cross reflection at night on the west coast mirrors,

which arises from the light emitted from the monitors being reflected off the side windows. The A-C/VIS interface was located on the left monitor housing, and allowed drivers to adjust the image brightness and amount of image processing, a feature termed "object-detection" that highlights the roadway and vehicles by tracing white lines around the edges of objects in the video image. An extended description of the A-C/VIS is presented in [6].

Preliminary testing with the A-C/VIS revealed that the optional turn signal lights mounted on the side of the Freightliner C-120 trucks could create a large bright spot on the monitors when activated. Translucent plastic guards were thus placed in front of the turn signal lights, not on top of them ([Figure 7](#)). These plastic guards lowered the amount of

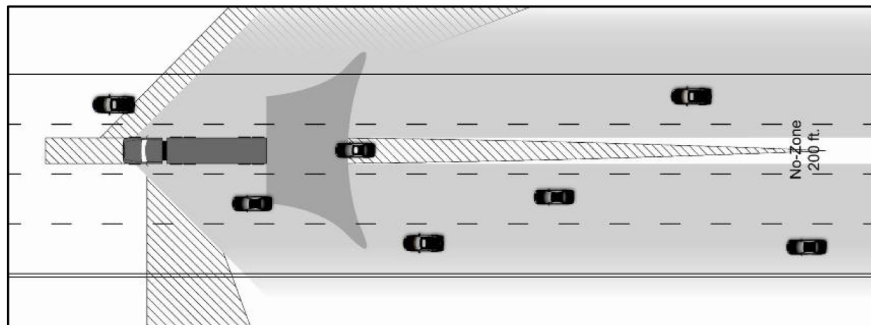


Figure 5. Coverage Provided by the Three A-C/VIS Cameras (Shown by Grey Shading)



Figure 6. Placement of A-C/VIS Monitors

light directly shined into the fender-mounted camera, reducing the size of the bright spot on the monitor from the turn signal light. The turn signal light diffusers, in addition to the A-C/VIS monitors' ability to be substantially dimmed, prevented large bright spots and discomfort glare from the turn signal lights.



Figure 7. Translucent Plastic Light Diffusers Mounted in Front of Optional Side Turn Signal Lights

DATA ACQUISITION SYSTEM (DAS)

The main DAS unit was mounted under the passenger seat of the truck and was constructed to automatically start when the truck's ignition was turned on. It consisted of a Pentium-based computer that received and stored data from the vehicle

network, forward and rear-facing radar systems, a video-based lane-tracking system, and a Global Positioning System (GPS). The collected data included vehicle speed, acceleration, brake pedal and turn signal use, range and range rate to lead and trailing vehicles, distance to lane markings, and vehicle position. Eight video images were also collected: four of the driver and four of the external environment. The DAS and instrumentation package used in this study were designed, developed, and enhanced during the last decade by VTTI. Previous versions of the system have been used in several on-road studies [8; 9].

EXPERIMENTAL DESIGN

This study investigated driver performance with C/VISs through a 2 (C/VIS) $\times$ 2 (Condition) mixed factors design. The two levels of the C/VIS between-subjects independent variable were the A-C/VIS and commercially available system. The two levels of the Condition within-subject independent variable were the Baseline condition (which consisted of one month of driving with the C/VIS disabled) and the Test condition (which consisted of three months of driving with the C/VIS enabled).

Dependent Variables

Participants' driving performance was assessed by analyzing their SCE rate, which has been defined as the number of SCEs encountered per 100 hours of driving [10]. Drivers'

clearance to an adjacent vehicle when initiating a lane change was analyzed to assess whether the clearance changed when driving with a C/VIS [11]. Drivers' visual behavior was analyzed to assess whether the C/VIS compelled drivers to look away from the road. The eye glance probability for a location was computed by summing the number of frames a driver looked in the location over a specified period of time and dividing this number by the total number of frames in this period of time [12]. Drivers' glance probabilities prior to encountering an SCE were computed using the 8 seconds prior to the SCE ($8 \text{ s} \times 10 \text{ frames/s} + \text{frame of SCE} = 81 \text{ frames}$), while drivers' glance probabilities during a lane change were computed using the interval of time spanning 8 s prior to the initiation of the lane change to 5 seconds after initiating the lane change ($13 \text{ s} \times 10 \text{ frames/s} + \text{frame of lane change initiation} = 131 \text{ frames}$). Finally, drivers rated how easy it was to be aware of surrounding vehicles by completing a questionnaire every two weeks during their participation.

PROCEDURE

Because there were only six routes at the Schneider National Winchester, Virginia operation that allowed the use of 48-ft-long trailers, and there were a limited number of drivers that were based out of Winchester, Virginia, drivers were recruited to participate in the study on a first-come, first served basis. After obtaining drivers' informed consent, an experimenter explained what a C/VIS was to the drivers, and then administered a questionnaire that measured drivers' opinions of their driving performance and the hypothetical C/VIS. Drivers were then assigned to one truck that had either an A-C/VIS or the commercial system installed. They drove one month with the C/VIS disabled (Baseline condition), and then three months with the C/VIS enabled (Test condition). Drivers completed questionnaires pertaining to their driving performance and the C/VIS they were using every two weeks. Drivers were compensated \$100 per week plus a \$100 bonus for completing questionnaires and cleaning the C/VIS fender cameras.

Technicians visited the trucks on a weekly basis to perform a health check of the data acquisition systems and C/VISs. The encrypted hard drives were transported back to the research institution where they were uploaded to a secure server. A series of quality control checks were then performed on the data and the results were used to identify additional maintenance issues.

Algorithms were then used to trigger potential SCEs. These algorithms were successfully used in previous naturalistic driving studies [8] and in general, identified events when the truck performed a hard deceleration or a swerve maneuver. Reductionists viewed the triggered events and verified whether an event was indeed an SCE. Valid SCEs were then reduced by one reductionist that recorded the environmental

conditions present, vehicle maneuvers that were performed, and whether the driver was distracted. The severity of the SCE was also determined. An SCE was classified as a crash if the truck made any contact with an object, either moving or fixed, at any speed. An SCE was classified as a near-crash if the circumstance required a rapid, evasive maneuver (e.g., hard braking, steering) by the participant, or any other driver, pedestrian, cyclist, or animal in order to avoid a crash. An SCE was classified as a crash-relevant conflict if the circumstance required a crash-avoidance response, but was less severe than a rapid evasive maneuver (as defined by near-crashes). Another reductionist then recorded the drivers' eye glance locations during the 10 s prior to the SCE and 5 s following the SCE.

An algorithm was developed and applied to identify potential lane change maneuvers. One reductionist inspected these lane change triggers and identified valid lane changes performed above 35 mph in which an adjacent vehicle was tracked by the side radar system. Eleven valid lane changes per driver, per week, were sampled. The same eye glance reductionist reduced drivers' visual behavior during the 10 s prior to a lane change and 5 s following the initiation of a lane change.

RESULTS

DRIVING DATA STATISTICS

A total of 412,417 km of driving data was collected, spanning a total of 5,161 hours, from the 12 drivers. The video and parametric data together comprise 3.35 Terabytes. In triggering events of interest from this data set, 277 unique SCEs were identified. Seventy percent of the SCEs were recorded at night. Ninety three percent of the SCEs were recorded during no adverse weather conditions. Forty-nine percent of the SCEs occurred with a traffic density equal to LOS A 13, which is indicative of free flow conditions, and 41 percent occurred in a traffic density of LOS B, which is indicative of stable traffic flow in the presence of other vehicles. Additional information on the recorded SCEs is presented in 2.

DRIVERS' INVOLVEMENT IN SCES

Drivers' involvement in SCEs was used to assess how well they operated a CMV. The hypothesis here was that a C/VIS may allow drivers to monitor the areas around the CMV and reduce the number, and/or duration, of the glances to the existing mirror system. Since drivers looking at the monitors do not have to turn their head as far as they do when looking at the west coast mirrors, it was hypothesized that drivers using a C/VIS would spend more time looking at the forward roadway, be less likely to miss an unfolding conflict, and experience fewer SCEs. A 2 (C/VIS) $\times$ 2 (Condition) Mixed Factors ANOVA was performed on the SCE rate dependent variable. The drivers' mean SCE rate of 5.2 in the Baseline condition ($\text{SEM} = 1.0$, $n = 12$, $\text{Min} = 0.0$, $\text{Max} = 10.7$) was