An observational study of the safety benefits of electronic logging devices using carrier-collected data

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Abstract

Objective: Fatigue has been shown to be a contributing factor in many large truck crashes. Long duty periods, irregular work schedules, and poor sleeping environments make fatigue a noteworthy concern in trucking operations. One way to limit fatigued driving is through prescriptive hours-of-service (HOS) regulations. This duty status information is typically recorded in written logs; however, more trucking companies are moving toward electronic HOS recorders. These devices were first marketed as productivity tools; however, more recently they have been touted for their safety benefits in reducing fatigued truck drivers (because falsifying electronic logs is difficult).

Methods: The purpose of the current study was to assess the benefits of electronic logging devices (ELDs) on safety and HOS violations in trucks as they operated during normal revenue service. Data on crashes, HOS violations, mileage, and onboard safety systems were obtained from participating motor carriers. Although the final data sets included data from 11 carriers representing medium and large carriers (including a total of 82,943 crashes, 970 HOS violations, and 224,034 truck-years that drove a total of 15.6 billion miles), the data set in the study was skewed toward larger, for-hire carriers and may not represent the overall U.S. trucking population.

Results: After controlling for calendar year, carriers in the data set, onboard safety system status, and long-haul/regional indicator, ELD-equipped trucks had a significantly lower total crash rate (11.7% reduction), preventable crash rate (5.1% reduction), driving-related HOS violation rate (53% reduction), and non-driving-related HOS violation rate (49% reduction) than trucks not equipped with ELDs.

Conclusion: The results show a clear safety benefit, in terms of crash and HOS violation reductions, for trucks equipped with ELDs.

Introduction

The Federal Motor Carrier Safety Administration (FMCSA) regulates the interstate truck and bus industry with the primary goal of reducing crashes, injuries, and fatalities. One of the key regulations that FMCSA enforces is a prescriptive hours-of-service (HOS) regulations, which are intended to ensure that truck and bus drivers have adequate time to obtain rest by limiting the number of hours per day and week a driver can drive/work. The goal of these regulations is to reduce fatigue and increase opportunities for sleep, thereby reducing associated crashes and improving driver health and wellness (FMCSA 2011). However, it is possible for drivers to violate HOS limits and falsify their paper records of duty status. Therefore, on April 5, 2010, FMCSA proposed the mandatory introduction of electronic logging devices (ELDs) to increase compliance with HOS regulations (FMCSA 2011). Whereas paper records of duty status rely on the driver to complete HOS information (e.g., hours driving), ELDs are Department of Transportation (DOT)-certified electronic hardware that connect to the vehicle’s engine to electronically record driving hours. It includes a screen for the driver so that he can monitor his current status and provides the ability to print logs when required by DOT inspectors.

ELDs for use in trucks and buses is not a new concept. The National Transportation Safety Board (1990) issued its first recommendation for the use of ELDs more than 30 years ago. In addition, a number of highway safety and advocacy groups have petitioned FMCSA in recent years to require the mandatory installation and use of ELDs in all trucks that are subject to HOS regulations (Advocates for Highway & Auto Safety 2010; Insurance Institute for Highway Safety 2011). ELDs were primarily designed to improve efficiency over standard paper logs; however, more recently they are being touted for their safety benefits in reducing fatigue. The rationale is that falsifying ELDs is difficult; thus, drivers are more likely to adhere to the HOS regulations.

Cantor et al. (2009) combined crash data from FMCSA’s Safety and Fitness Electronic Records and HOS violations from the FMCSA’s Safety Management Measurement System to model the potential impact of full ELD adoption on crashes and HOS violations. In this study, the authors found that full ELD adoption could potentially reduce HOS violations by 12.4% and total crashes by 15.6%. Moreover, FMCSA (2010) estimated that ELDs have the potential to reduce HOS violations by up to 40%.

The current study addressed several of the limitations in Cantor et al. (2009) and FMCSA (2010). First, the current study...
used carrier-collected crash data to obtain a more representative picture of how ELDs perform under real-word driving conditions. Second, the analysis was at the truck level; thus, trucks equipped with ELDs were compared to trucks without ELDs. Third, a measure of exposure was calculated (vehicle miles traveled or VMT) at the truck level. Fourth, vehicle information was collected so that we could control for other safety features on the truck and identify whether (and when) an ELD was installed on the truck. The data collected from participating carriers were used to answer 2 specific hypotheses:

- **Hypothesis 1:** Trucks equipped with an ELD will have a significantly lower crash rate than trucks without an ELD.
- **Hypothesis 2:** Trucks equipped with an ELD will have a significantly lower HOS violation rates than trucks without an ELD.

### Data overview and methods

The data collection effort in the current study involved the assemblage of existing carrier-owned data by the research team. This effort was designed to assess the potential safety benefits of ELDs in reducing the frequency and severity of crashes and HOS violations. These data included carrier, crash, HOS violation, and vehicle information in calendar years 2008 to 2012. The Appendix (see online supplement) shows the list of the required data elements included in the study. Carriers that did not provide these data elements were excluded from participating.

### Data collection

Collection of carrier data began after the nondisclosure agreement was signed and returned by the participating carrier. After the nondisclosure agreement was returned, the research team worked with each carrier’s representative to collect the necessary data. Specific carrier information was also gathered from these carrier representatives, including general carrier information and use of ELDs. The research team recruited carriers that had class 7 and 8 trucks (gross vehicle weight from 26,001 to 33,000 lbs and over 33,000 lbs, respectively) with and without ELDs. Those vehicles that solely performed local, short-haul deliveries within a 150-air-mile radius were not included in the analyses.

HOS violation data for each carrier were collected via FMCSA’s Safety Management System (SMS) online web page, and these were the only HOS violations used in the data analyses. This ensured standard HOS violation data across all carriers and allowed comparisons with other studies using these data. However, the SMS web site only provided data for 2 years prior to the date of retrieval. More specifically, HOS violation data were only collected from a small portion of 2010 and all of 2011 and 2012. Furthermore, HOS violations were not collected from carriers F and G. Carrier F only provided data for calendar years 2008 and 2009; thus, HOS data were not available for those years. Carrier G’s HOS violation data were not included because there were issues matching the vehicle identification numbers (VINS) to the vehicle data set.

Of critical importance was potential bias in the installation of ELDs on trucks and whether the ELDs were actually used to track the drivers’ HOS. Carrier personnel at each participating carrier were asked to describe the approach (if any) for installing an ELD on a truck and whether they used the ELDs to track the driver’s HOS. Only one carrier indicated a systematic approach to installing ELDs, the rest of the carriers indicated a random approach. The research team determined that the data from carrier K were systematically biased because they targeted new drivers’ trucks for installation of an ELD. For this reason, carrier K was excluded from all analyses.

### Data merging and reduction

Because the data sets provided by each carrier were not identical, all data sets were merged and formatted into one large data set with common variable headings (e.g., crash scenario). The data analysts identified crashes where fatigue was a contributing factor. The individual crash files provided by the participating carriers included a primary contributing factor (i.e., the most likely reason for the crash). Therefore, all crashes containing the words `fatigue`, `fatigued`, `sleep`, `asleep`, `sleepy`, `drowsy`, `drowsiness`, or `tired` as the primary contributing factor were identified as a fatigue-related crash. Additionally, a keyword search of the crash narratives for each crash was conducted. This keyword search filtered crash files using the same terms as above. Furthermore, the data analysts reviewed specific crash types that occurred during the circadian low between 2:00 a.m. and 6:00 a.m. These crash types included sideswipe, opposite sideswipe, run off road, head-on, rollover, jackknife, hit fixed object, and broadside (Price 2005; Stutts et al. 2003).

Carriers also made a determination regarding whether the crash was preventable. A preventable crash is one in which the carrier driver failed to exercise every reasonable precaution to prevent the crash. This is not the same as at-fault, which is a legal determination. This is irrespective of whether or not there was property damage or personal injury, the extent of the loss of injury, to whom it occurred, and the location of the crash.

HOS violations were also divided into 2 categories: Driving-related and non-driving-related violations. Driving-related violations included 11-hour rule violation, 14-hour rule violation, 16-hour rule violation, and 60/70-hour rule violation. Non-driving-related violations included driver’s record of duty status not current, log violation (general/form and manner), driver failing to retain previous 7 days of logs, false report of driver’s record of duty status, no driver’s record of duty status, no log book, and malfunctioning ELD. If a driver had multiple violations on the same inspection, each violation was treated separately and not as one violation. See FMCSA (n.d.) for a list of all HOS violations.

The vehicle, crash, and HOS data sets were linked by the truck’s VIN. Approximately 90% of the crashes were matched to a specific truck in the vehicle data set; however, only 60% of the HOS violations were matched to a specific truck in the vehicle data set. Those crashes and HOS violations that could not be linked to a specific truck were excluded from all analyses. The date of ELD installation (if installed) was used to partition the data. All data prior to the date of ELD installation were treated as if the truck did not have an ELD (and vice versa for the date of ELD installation and after).
Statistical approach

The safety benefits of ELDs were quantitatively evaluated by comparing the crash risk for 2 exposure groups: trucks with ELDs (yes) or without ELDs (no). The primary response variable for risk assessment was crash frequency. Correspondingly, the count-based Poisson regression model was used to model the crash count data. The number of crashes for carrier \( i \), truck \( j \), \( Y_{ij} \), was assumed to follow a Poisson distribution as shown below:

\[
Y_{ij} = \text{Poisson} \left( E_{ij} \lambda_{ij} \right),
\]

where \( Y_{ij} \) is the number of crashes for carrier \( i \), truck \( j \), during the study period; \( E_{ij} \) is the mileage traveled for truck \( j \) in carrier \( i \); and \( \lambda_{ij} \) is the expected crash rate. The expected crash rate \( \lambda_{ij} \) was the primary measure to evaluate the crash risk of a truck. A log link function was used to connect this crash rate to a set of independent variables; that is,

\[
\log (\lambda_{ij}) = \beta_0 + \beta_1 X_{1ij} + \cdots + \beta_K X_{Kij},
\]

where \( X_{kij} \) is the variable based on a risk factor \( k \) for truck \( j \) in fleet \( i \) and \( \beta_k \) is the corresponding regression coefficient. The ELD status of a truck was represented by a binary variable as follows:

\[
X_{EHSRij} = \begin{cases} 1 & \text{if truck } ij \text{ was equipped with an ELD} \\ 0 & \text{if truck } ij \text{ was not equipped with an ELD} \end{cases}
\]

The inference was conducted based on the corresponding regression coefficient \( \beta_{EHSR} \). There was no evidence of overdispersion or lack of fit in the Poisson model (e.g., the deviance over degrees of freedom was smaller or close to 1.0, and fitting the negative binomial regression model indicated that there was no need for an overdispersion parameter). Therefore, the research team considered the Poisson model as appropriate and sufficient for the analysis. Safety equipment, such as onboard safety systems (OBSS; e.g., forward collision warning systems, etc.), were covariates in the same model. The output of this model was the effect of ELDs adjusted for other factors. The safety of a carrier is often affected by safety culture, safety management strategies, and the nature of their business operations. As such, trucks in the same carrier are more likely to share similar risk profiles. The research team used a fixed-effect term to represent the base crash level for a carrier.

Table 1. Number of truck-years in the ELD and non-ELD cohorts by carrier.

| Carrier | ELD truck-years | Non-ELD truck-years |
|---------|-----------------|---------------------|
| A       | 2,096           | 6,263               |
| B       | 5,369           | 4,596               |
| C       | 37,764          | 23,914              |
| D       | 0               | 6,585               |
| E       | 0               | 16,559              |
| F       | 0               | 418                 |
| G       | 0               | 42,361              |
| H       | 0               | 1,306               |
| I       | 3,746           | 16,488              |
| J       | 14,083          | 9,380               |
| L       | 20,107          | 12,999              |
| Total   | 83,165          | 140,869             |

Results

The final data set included data from 11 carriers with 224,034 truck-years, 82,943 crashes, and 970 HOS violations. These trucks drove a total of 15.6 billion miles. Truck-years do not reflect the number of mutually exclusive trucks over the 5 calendar years but rather the number of trucks over the 5 years of data collection. As shown in Table 1, 6 carriers had an ELD installed in a portion of their trucks at some time during the study period (2008 to 2012).

Table 2 shows the years of data, truck-years, million vehicle miles traveled (MVMT), number of crashes, crash rate, number of HOS violations, and the HOS violation rate. As shown in Table 2, there are different mileages for crashes and HOS violations. This is because HOS violations were only collected from 2 years prior to data collection (they do not include carriers F and G, as indicated above).

Table 3 shows the crash type, MVMT, and the crash rate for each cohort. Preventable, DOT-recordable, and fatigue-related crashes were not mutually exclusive. Due to the number of HOS violations, HOS violations were separated into driving-related and non-driving-related violations, individual HOS violations were not evaluated. Table 4 shows the HOS violation type, MVMT, and the HOS violation rate.

Formal statistical inference was conducted using the Poisson regression model. All models included potential effect modifiers, including year, carrier index, OBSS status (yes/no), and long-haul/regional indicator. The effect of ELDs was measured by the crash rate ratio between ELD- and non-ELD-equipped trucks. The crash rate ratio was the exponent of the Poisson
Table 3. Crash rates by ELD cohort.

| Crash type         | ELD cohort crash count(A) | ELD cohort MVMT(B) | ELD cohort crash rate(A/B) | Non-ELD cohort crash count(C) | Non-ELD cohort MVMT(D) | Non-ELD cohort crash rate(C/D) |
|--------------------|---------------------------|--------------------|---------------------------|-------------------------------|------------------------|-------------------------------|
| Preventable        | 14,537                    | 6,048              | 2.40                      | 24,985                        | 9,555                  | 2.61                          |
| U.S. DOT-recordable| 3,197                     | 6,052              | 0.53                      | 5,729                         | 9,543                  | 0.60                          |
| Fatigue-related    | 328                       | 6,054              | 0.05                      | 659                           | 9,540                  | 0.07                          |
| Total crashes      | 29,093                    | 6,046              | 4.81                      | 53,850                        | 9,559                  | 5.63                          |

Table 4. HOS violation rates by ELD cohort.

| HOS violation type | ELD cohort (A) | ELD cohort MVMT(B) | ELD cohort HOS violation rate(A/B) | Non-ELD cohort HOS violation count(C) | Non-ELD cohort MVMT(D) | Non-ELD cohort HOS violation rate(C/D) |
|--------------------|----------------|--------------------|------------------------------------|---------------------------------------|------------------------|---------------------------------------|
| Driving-related    | 51             | 5,760              | 0.01                               | 97                                    | 2,912                  | 0.03                                 |
| Non-driving-related| 232            | 5,760              | 0.04                               | 480                                   | 2,912                  | 0.16                                 |

Table 5. Crash rate comparison between the ELD and non-ELD cohorts.

| Crash type         | Crash rate ratio (ELD vs. non-ELD cohorts) | Standard error | 95% Confidence interval lower bound | 95% Confidence interval higher bound | Chi-square | P value |
|--------------------|--------------------------------------------|----------------|------------------------------------|-------------------------------------|------------|---------|
| Preventable        | 0.95                                       | 0.0165         | 0.92                               | 0.98                               | 10.13      | .001    |
| U.S. DOT-recordable| 0.99                                       | 0.0358         | 0.92                               | 1.06                               | 0.08       | .781    |
| Fatigue-related    | 0.99                                       | 0.1056         | 0.80                               | 1.22                               | 0.01       | .926    |
| Total crashes      | 0.88                                       | 0.0117         | 0.86                               | 0.90                               | 112.63     | <.001   |

Table 6. HOS violation rate comparison between the ELD and non-ELD cohorts.

| HOS violation type | HOS violation rate ratio (ELD vs. non-ELD cohorts) | Standard error | 95% Confidence interval lower bound | 95% Confidence interval higher bound | Chi-square | P value |
|--------------------|----------------------------------------------------|----------------|------------------------------------|-------------------------------------|------------|---------|
| Driving-related    | 0.47                                               | 0.2940         | 0.26                               | 0.83                                | 6.69       | .010    |
| Non-driving-related| 0.51                                               | 0.1369         | 0.39                               | 0.66                                | 24.71      | <.001   |

Discussion

Whereas other studies assessed the potential safety benefits of ELDs without a scientific study, with surveys, or with crash rates obtained from large national or state crash databases (Can- tor et al. 2009; Cullen 2007; FMCSA 2010; Insurance Institute for Highway Safety 2011; Kraft 2011; McCartte et al. 2008), the current study used data collected from directly from carriers to determine the efficacy of ELDs. The approach used in this research went beyond previous studies in this domain. First, the current study used motor carrier data from participating carriers; thus, the resultant data set used in the analyses contained a broad spectrum of crashes, many of which were not required to be reported to state or federal agencies; thus, they reflect a carrier's actual crash spectrum. Second, the research team collected detailed information on the trucks, thereby allowing the identification of trucks with and without an ELD installed. Information on the OBSSs installed on each truck was also collected, which allowed the research team to control for systems that may have influenced the crash rate. Third, the research team collected mileage information from each truck to control for differences in exposure.

The results across analyses indicated a strong, positive safety benefit for ELDs in relation to total crashes, preventable crashes, driving-related HOS violations, and non-driving-related HOS violations. Trucks equipped with ELDs had total crash and
preventable crash rates (per MVMT) that were significantly lower than the rates for trucks not equipped with ELDs. No differences were found between the ELD cohort and the non-ELD cohort for U.S. DOT-recordable and fatigue-related crash rates. This result is primarily attributed to the lack of sufficient data (in terms of the number of these types of crashes) to be able to detect safety benefits with statistical significance at the observed level. In addition, for fatigue-related crashes, the research team was missing critical information (hours slept prior to the crash, last rest period, and driving hours in current shift) to assess whether fatigue was a contributing factor; thus, fatigue-related crashes were underreported because several studies have found fatigue to be a contributing factor in 14 to 30% of truck crashes (FMCSA 2006; Knipling and Wang 1994). In terms of HOS violations, trucks equipped with ELDs had driving-related and non-driving-related HOS violation rates (per MVMT) that were significantly lower than the rates for nonequipped trucks.

Results from this study support the notion that ELDs increase safety and compliance with HOS regulations. Although proponents of ELDs reported safety or HOS compliance benefits, little scientific data were provided to support their statements (Fuetsch 2012; Kraft 2011; Kvidera 2011; Werner Enterprise, n.d.; XRS Corporation 2012). Results from this study are in the middle of the range (12 to 70%) of the reported HOS violation reduction. The study completed by Cantor et al. (2009) estimated a 15.6 and 12.4% reduction in crashes and HOS violations, respectively, with 100% ELD adoption using a survey approach combined with national crash and HOS data. The current study found similar reductions in the crash rate but a far greater reduction in HOS violations (driving- and non-driving-related). The Cantor et al. (2009) study included a far more representative sample of carriers than the current study; however, the authors were not able to include exposure, nor could they identify which trucks were equipped with an ELD. Although the current study was able to precisely identify trucks equipped with an ELD and include the specific yearly mileage for each truck, the results were skewed toward larger, for-hire carriers and may not reflect the general carrier population.

Results presented by the XRS Corporation (2012) cite an Aberdeen Group study of companies currently using ELDs to record and manage drivers’ HOS compliance. The Aberdeen Group asserts that companies using ELDs experienced a 27.9% increase in HOS compliance. The current study also found that ELDs reduce HOS violations (53 and 49% significantly lower driving-related and non-driving-related, respectively); however, the current study found an even greater reduction in HOS violations than the XRS Corporation (2012). The XRS Corporation (2012) did not provide the methodology or data from the Aberdeen Group study. Thus, it is impossible to validate the increase in HOS compliance.

Cullen (2007) presents Shaw Industries’ experiences with ELDs. Between March 2004 and March 2007, Shaw Industries experienced a 53% reduction in HOS violations per month with the use of ELDs. Furthermore, Shaw Industries’ out-of-service rates and driver out-of-service inspections were reduced 72 and 47%, respectively. The current study found similar reductions in HOS violations with ELD use. Although the reductions presented in Cullen’s (2007) study show reductions in HOS violations, the article does not present the methodology used to determine the effectiveness of ELDs. Additionally, it is unknown whether confounding factors were controlled for in the analyses. Thus, the results presented in Cullen’s (2007) study cannot be validated and may not reflect the true effects of ELDs. Taken together, the current study and the other 3 studies presented clearly show a safety benefit for ELDs with respect to crashes and HOS violation. Because this was an observational study, we are unable to determine why these reductions occurred but only that trucks with an ELD were more likely to experience these benefits compared to trucks without an ELD. Thus, based on these results, FMCSA’s (2015) mandate for ELDs on trucks is likely to increase safety and HOS compliance.

Although the current study involved the collection of comprehensive truck, carrier, crash, and HOS violation information, the carrier-collected data relied on retrospective crash reconstruction. This information can be erroneous for a variety of reasons, such as eyewitness recall, limited precrash information, and unwillingness to report information for fear of prosecution, termination, or reprimand. A video-based naturalistic truck study would address these concerns. The current study design could be expanded to include a larger, more representative sample. Although there were 224,034 truck-years, 82,943 crashes, and 970 HOS violations in the data set, the number of fatigue-related crashes represented a small portion of these (0.44 and 15.3%, respectively). Furthermore, analyses could be rerun using HOS violations over a longer period of time (because only the previous 2 years’ worth of HOS violations were collected in the current study) using archived data from FMCSA that were not available on the SMS website. Finally, the majority of participating carriers in the current study were large, for-hire carriers. An additional study with small-to-medium carriers (i.e., carriers with less than 250 power units) could be performed.

**Limitations**

Although the data set used in the analyses to assess the potential safety benefits of ELDs was comprehensive, there were several limitations. The data set in the current study was skewed toward larger, for-hire carriers (only two private fleets participated) and may not represent the overall U.S. trucking population. One factor that was not included was driver characteristics, which might affect the crash rate. Due to the high turnover rate in the trucking industry, it was difficult to associate a particular truck with all its drivers. Therefore, the analysis was based on trucks and did not factor in driver characteristics. Although the research team had no information on the functionality of each ELD installed on a truck (i.e., the research team could not verify whether the ELD was malfunctioning), the team did assess whether the ELDs were being used by each carrier to monitor drivers’ HOS compliance. No driver information was used in the analyses; thus, it is possible that a few drivers were over-represented in the crashes and the differences in the crash rates may have been the result of these drivers and not the ELDs. The design was quasi-experimental and subject to many threats to inferential validity. The results in the current study could be confounded by factors that vary between carriers. Information on these factors was collected; however, it is possible that variables not collected may have confounded the results. HOS violation data were collected from FMCSA’s SMS. During analyses it was determined that a large percentage of VINs did not match the VINs in the vehicle data set (most likely due to human error in
recording the VIN). The nonmatching trucks that had HOS violations could have impacted the HOS violation results (either supporting the current analyses or vice versa).

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