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NSTSCE

National Surface Transportation Safety Center for Excellence

Evaluation of an In-vehicle Monitoring System Among an Oil and Gas Well Servicing Fleet

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The NSTSCE stakeholders have jointly funded this research for the purpose of developing and disseminating advanced transportation safety techniques and innovations.

EXECUTIVE SUMMARY

The primary objective of this analysis effort was to determine if an in-vehicle monitoring system (IVMS) affected the driving performance of a group of workers employed by one well servicing company. The secondary objective was to discover if and how IVMS event tracking and naturalistic data can be applied to classify the oil and gas transportation operations of light trucks.

To support this effort, IVMS data were analyzed, including safety event data collected on 21 fleet vehicles and driver behavior on traceable route data collected on four participant drivers' vehicles.

DATA COLLECTION

This naturalistic evaluation of an IVMS was conducted among a fleet of oil and gas well servicing vehicles. Data collected from the fleet was handled anonymously across 21 IVMS-instrumented light vehicle pickup trucks (GMC 2500s and Ford F-250s). Data were also collected on a sample of four participating drivers whose vehicles were instrumented with an IVMS and a miniature data acquisition system (MiniDAS). Drivers of these vehicles included a mixture of well-site foremen, well-site crew drivers, and a fleet safety manager who visited the well sites.

The IVMS collection of anonymous fleet vehicle activity data covered 141,312 miles and 3,500 hours (209,977 minutes) across 21 vehicles. The IVMS collection of trip-specific information on the MiniDAS vehicles captured specific trip information across 45,025 miles and 1,026 hours (61,608 minutes) of vehicle activity across four vehicles.

IN-VEHICLE MONITORING SYSTEM PERFORMANCE

The IVMS collection of anonymous speeding and aggressive driving performance was analyzed to determine if the IVMS affected the fleet when compared between a baseline period, no IVMS feedback, and an intervention period with weekly IVMS reports delivered to drivers and managers.

The baseline and intervention periods had a total of 21 matched vehicles. These vehicles and their drivers demonstrated a 60% reduction in speeding events from the baseline period to the intervention period. They also demonstrated a 50% reduction in aggressive driving events from the baseline period to the intervention period. These reductions were both statistically significant.

DRIVER FEEDBACK

Questionnaires on the IVMS were collected from a sample of drivers who consented to participate and provide feedback on the system. The opinions of the drivers remained neutral to positive after the study was completed. Drivers also rated the functionality of the IVMS positively.

TRANSPORTATION ACTIVITY AND ROAD TYPE

Specific vehicle activity, such as trips and locations, was collected on a sample of four drivers who consented to having their vehicles tracked for IVMS safety event performance

and GPS coordinates. The transportation activity varied between one driver, who was a fleet safety manager, and three other drivers, whose roles were site foremen and site crew.

The average number of on-duty days collected among the three site drivers was 72 days. The average daily commute distance was 147.6 miles. The average on-duty hours for the three drivers was 12.5 hours per day, and the average daily commute was 2.9 hours per day. The combined average daily on-duty and commute time was 15.4 hours, which demonstrates the long hours that these well servicing workers put in daily.

Drivers spent roughly 12% of their total driving time on private or public unimproved roadways. This amounted to over 100 hours of non-idle time on dirt roadways over the 3-month data collection period. These roadways offer their own set of hazards that are not encountered during typical on-highway driving.

DRIVING BEHAVIORS

An in-depth investigation into speeding and aggressive-maneuver behaviors was evaluated for the four participating drivers in a manner similar to the evaluation performed for the fleet-wide analysis. Particularly, speeding and hard braking were evaluated on off-highway roadways to understand driving patterns. While on-highway speeding accounted for roughly 2% of the total driving time for the participant drivers, speeds above 30 mph exceeded 25% of all unimproved road driving. However, hard braking events were less likely to have occurred off-highway (1.1 vs. 4.3 events per 1,000 minutes).

CONCLUSIONS

This pilot project demonstrated the utility of IVMSs and naturalistic data. Examining a small number of individuals' daily driving styles and habits along with route-related information results in a wealth of data for use in identifying answers to future industry questions.

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ACRONYMS AND ABBREVIATIONS

IVMS	in-vehicle monitoring system
MiniDAS	miniature data acquisition system
NIOSH	National Institute of Occupational Safety and Health
NSTSCE	National Surface Transportation Safety Center for Excellence
OBD-II	On-board Diagnostics port (Version 2)
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

During the last 15 years, the oil and gas extraction industry has undergone tremendous growth. Between 2003 and 2013, the number of active drilling rigs increased by 70% and the number of workers increased twofold (Mason et al., 2015). The oil and gas extraction industry has an elevated fatality rate, resulting primarily from fatal transportation events and working with heavy tools and equipment. At present, little is known about the risk factors associated with transportation incidents in this industry (Retzer et al., 2013). Driver monitoring systems, or in-vehicle monitoring systems (IVMSs), hold promise for supporting the industry with systems that can create traceability and accountability for transportation activities. This report describes a naturalistic study that evaluated the effects of one IVMS on one fleet's performance and sought to understand risks that exist in the field through the recording of driver behaviors, vehicle near-miss incidents, and driver schedules.

PROBLEM STATEMENT

The average annual fatality rate from 2003 to 2013 among oil and gas extraction workers (25.1 per 100,000) is more than six times the rate among U.S. workers in general (3.7 per 100,000). Furthermore, motor vehicle incidents were the leading cause of death for oil and gas extraction workers, constituting 40% (1,159) of all fatalities during the same period (Mason et al., 2015). In a previous study of motor vehicle fatalities, based on data gathered between 2003 and 2008, the proportion of transportation-related fatalities was especially high in the oil and gas extraction industry (7.6 per 100,000) compared to other industries, such as construction (1.7 per 100,000; Retzer et al., 2011). Furthermore, the same study found that the most common types of vehicle involved in fatal incidents were pickup trucks (51.5%) followed by semi-trucks (26.7%), and that seat belt non-use was reported in 38.1% of the fatalities.

The fact that roads near well sites are typically unimproved and lack safety features may contribute to transportation-related oil and gas worker fatalities. In addition, drivers often travel long distances to and from well sites and work long hours at those sites. These factors all highlight the need to better understand the various elements that lead to oil and gas extraction workers' transportation-related injuries and fatalities.

BACKGROUND

Due to the high rate of fatalities related to motor vehicle incidents among oil and gas extraction workers, public health practitioners have called for the following steps to be taken: further research into the oil and gas extraction industry's motor vehicle safety practices, industry cooperation in developing motor vehicle safety programs, and increased application of IVMSs.[(2)] In response, the National Surface Transportation Safety Center for Excellence (NSTSCE) and the National Institute of Occupational Safety and Health (NIOSH) sponsored a naturalistic driving study through the Virginia Tech Transportation Institute (VTTI). The study involved light vehicles (GMC Model 2500 and Ford F-250 pickup trucks) from an oil and gas well servicing fleet in western Colorado. For data collection, IVMSs installed on 23 of the fleet vehicles actively collected driver performance data, including vehicle dynamics, and recorded safety/efficiency-related events, such as hard braking, rapid acceleration, speeding, idling time, and nighttime driving. Simultaneously, five vehicles were equipped with IVMSs and miniature data acquisition systems (MiniDASs) that continuously collected naturalistic data such as video, vehicle dynamics, and GPS data (see Table 1). Upon review of the collected data, 21 driver-anonymous vehicles had sufficient data for analysis of the IVMS performance and 4 vehicles had sufficient data for analysis of transportation activity and future naturalistic reduction.

Table 1. Vehicle count with equipment and sufficient data by driver group type.

Driver Group Type	Equipment	Vehicles Instrumented	Vehicles with Sufficient Data
Fleet Anonymous	IVMS	23	21
Participant Sample	IVMS + MiniDAS	5	4
	Total	**28**	**25**

CHAPTER 2. METHODS

A before-and-after IVMS feedback activation approach was applied to evaluate the effects of the IVMS on an upstream oil and gas well servicing fleet. During the baseline (before) period, the IVMS was active but drivers and managers were not informed of drivers' performance. During the intervention (after) period, performance feedback was provided to drivers and managers. A transition period of 3 weeks occurred between the baseline and intervention periods. This was a result of the time it took the IVMS vendor and fleet to train the whole fleet of drivers and managers on the IVMS technology operations and reports.

FLEET DESCRIPTION

The well servicing company is located in western Colorado. The company provides completion and workover services, include drilling, cleaning out, fishing, and other tasks. The fleet operates approximately 30 well servicing rigs in the western Colorado and eastern Utah region. These rigs can remain stationary at the same well site for extended periods of time. Therefore, the well servicing crew and foreman (tool pusher), who manage the job and equipment, commute from their homes or the local yard (or office) to the well site daily. The crew and the foreman often drive separate vehicles, which are generally light vehicle pickup trucks (e.g., GMC 2500s, Ford F-250s), to the sites (see Figure 1). These vehicles include 4-door cabs for the crew and 2-door or 4-door cabs for the foreman. Due to the nature of the operation, the pickup trucks are assigned to drivers, who take them home and are allowed to use them for personal reasons as well. At the time of the data collection, there were approximately 15 to 17 heavy vehicle rigs active in the field with approximately 30 light vehicle pickup trucks engaged in supporting field operations.

Figure 1. Photo. Oil and gas well servicing fleet vehicles.

IN-VEHICLE MONITORING SYSTEM

The IVMS used during this evaluation was the ROVR™, developed by the technology vendor Cartasite®, Inc. The IVMS device is a small box that connects to vehicles through the on-board diagnostic (OBD-II) port (see Figure 2), and is used to communicate with the vehicle network. The device is capable of tracking vehicle location based on GPS latitude and longitude coordinates, and vehicle motion based on changes in vehicle acceleration along forward-rearward and lateral axes. The IVMS device communicates vehicle status and location through cellular networks. Additional equipment can be mounted to the IVMS at a fleet's request to provide drivers with login capability and audible system feedback for safety events, such as excessive speeding above a set vehicle limit and aggressive driving maneuvers. However, these add-on components were not installed during this study.

Figure 2. Photo. IVMS OBD-II connector device.

The IVMS records scheduled vehicle status events and unscheduled events for safety and tracking purposes. The scheduled events and GPS coordinates are collected every minute following the vehicle's first movement status, which typically occurs within the first minute following vehicle ignition and motion. These scheduled vehicle status events are reported as either "movement" or "speeding (minor/moderate/severe)." Vehicle speeds captured every minute are compared by the system offline to posted speed limit maps based on GPS location.

Other events are unscheduled and based on vehicle ignition and maneuvers. These unscheduled events include departure, arrival, and change in direction, as well as aggressive driving maneuvers, including hard braking, rapid acceleration, and lateral acceleration. In addition, the vehicle speed is recorded at unscheduled times if it exceeds the maximum vehicle speed as set between the fleet and the IVMS vendor.

Events such as departure, movement, change of direction, and arrival can be sequenced to construct trip times and locations. Events such as speeding, hard braking, rapid acceleration, and lateral acceleration can be applied to measures of safe driving performance. The IVMS records the location of these safety-related events with GPS coordinates. The IVMS event descriptions and thresholds are provided in Table 2.

Table 2. IVMS vehicle safety event and vehicle status event thresholds and descriptions.

<table>
<tr><th colspan="4">Scheduled Vehicle Status Events</th></tr>
<tr><td>Movement Status</td><td colspan="3">Vehicle status recorded every minute after first vehicle motion event. This typically initiates within 1 minute of departure.</td></tr>
<tr><td>Speeding Status</td><td colspan="3">Vehicle speed from Movement Status compared to posted speed limit based on GPS coordinates. Maximum Rate: 60 events per hour.</td></tr>
<tr><td rowspan="2">Vehicle Speeding Thresholds</td><td>Speeding, Minor</td><td>Speeding, Moderate</td><td>Speeding, Severe</td></tr>
<tr><td>6 mph or more above posted limit</td><td>11 mph or more above posted limit</td><td>20 mph or more above posted limit</td></tr>
<tr><th colspan="4">Unscheduled Vehicle Status Events</th></tr>
<tr><td>Arrival/Departure</td><td colspan="3">Based on vehicle ignition and motion.</td></tr>
<tr><td>Change of Direction</td><td colspan="3">Vehicle direction based on GPS heading change > 75 degrees.</td></tr>
<tr><td>Excessive Speeding</td><td colspan="3">Vehicle exceeds fleet-selected maximum speed threshold, ≥ 80 mph.</td></tr>
<tr><td rowspan="2">Aggressive Driving Thresholds</td><td>Hard Braking</td><td>Rapid Acceleration</td><td>*Lateral Acceleration</td></tr>
<tr><td>−2.4 m/s/s; lasting ≥ 0.050 s</td><td>+ 2.4 m/s/s; lasting ≥ 0.050 s</td><td>± 3.5 m/s/s; lasting ≥ 0.300 s</td></tr>
<tr><td colspan="4">* Note: Lateral acceleration events were not provided with the fleet data.</td></tr>
</table>

The IVMS vendor provides performance feedback to the fleet managers and drivers through a Web portal and weekly emailed reports. Individual drivers are assigned scores based on their performance. The Web portal can be used to view the safety events and vehicle status by time and location. A sample of the Web portal is shown in Figure 3, which demonstrates the level of detail that can be provided to fleet managers to support improving driver performance. The colors of the icons on the map represent different events, such as speeding, hard braking, movement, or change of direction. This sample was collected prior to the study during system shakedown testing near VTTI's research center. Geo-fenced zones can also be created using the Web portal. A zone was created for the home site and a nearby road, as indicated in the sample image in Figure 3 with green (circle) and yellow (right angle) highlighted areas respectively.

A distinctive attribute of this IVMS is the use of GPS coordinates to provide vehicle and well-site location information on the same maps where vehicle events are recorded for each driver. These well sites have provided valuable information about the daily operations of the well servicing drivers.

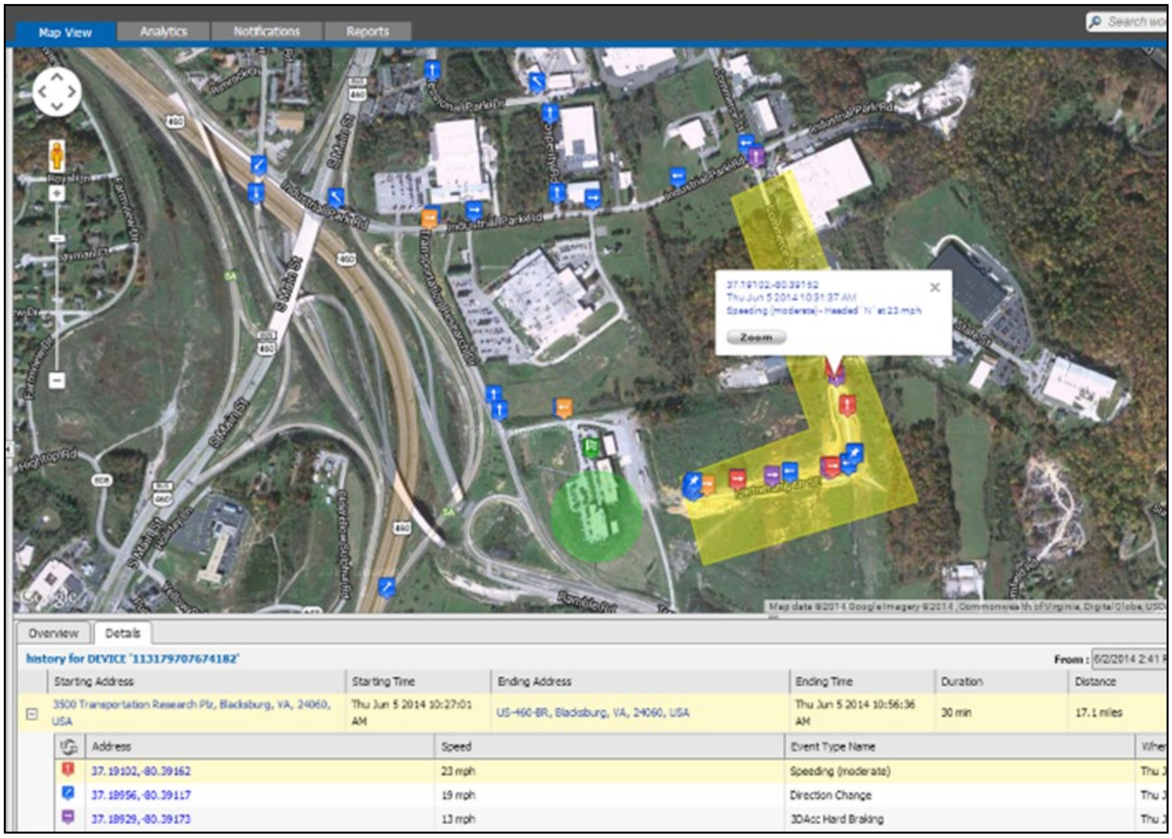

Figure 3. Map. IVMS demonstration of the Manager Portal during a test drive near the VTTI research center.

COLLECTION DESCRIPTION

Two types of instrumentation data were collected during the study: discrete intermittent data with the IVMS and continuous naturalistic data with the VTTI MiniDAS. The IVMS data were collected on the entire fleet and delivered to VTTI after the study was completed. Two levels of information were collected with the IVMS, which differed based on driver participation: fleet-wide data and driver-specific data. First, the IVMS data included vehicle-only generic (driver anonymous) safety event data across a majority of the fleet. Second, driver-specific IVMS safety event data and IVMS trip and route GPS coordinates were collected among a sample of participating drivers' vehicles. The baseline period was designed to last approximately 1 month. The intervention period was designed to last approximately 2 months. The collection was completed over the calendar period of July–October 2014.

The well servicing fleet and the IVMS vendor granted VTTI access to anonymous driver IVMS data collected on 23 IVMS-instrumented fleet trucks. Two of the vehicles among the anonymous drivers did not have sufficient data. Therefore, 21 anonymous driver vehicles were included in the analysis of the IVMS's performance.

VTTI was granted access by participant consent to driver-traceable IVMS data on five instrumented trucks. The drivers who consented to participate also provided subjective feedback about the IVMS as well as some details about their daily operations. One of the participating drivers left the fleet during the study. A replacement driver who was assigned to that instrumented vehicle consented to participate; however, a combination of study timing and equipment malfunction rendered this replacement participant's vehicle data unusable for analysis. Therefore, four identifiable participant vehicles were included in the analysis of transportation activity. Among the four participants, one driver was a manager who was active around the fleet site and occasionally around well sites, two drivers were site foremen, and one was a site-crew driver.

DATA ANALYSIS

The following section details the results of the IVMS evaluation with participant fleet drivers. Primary analyses include one-sample and paired-sample *t*-tests of means. Additionally, when data suggested a violation of the assumption of normal distribution, a Wilcoxon signed rank test of medians was used. These analyses provide *t*-statistics and *p*-values when performing *t*-tests, and a *W*-statistic when performing the Wilcoxon signed rank test.

The data analyses applied to this evaluation of the IVMS's effectiveness on fleet driving performance and transportation activity assumed that the driver was consistent across the collection period. Efforts were made to trace IVMS devices, which were assigned to fleet vehicles anonymously to ensure that the vehicle scores were consistent throughout the collection period. The fleet informed the research team that the vehicles instrumented for the participating drivers were assigned to those drivers. Furthermore, the research team had monthly interaction with the participating drivers to check on system function and exchange collection memory cards in the VTTI MiniDAS.

Fleet In-Vehicle Monitoring System Events

The IVMS devices were installed on the fleet of vehicles across the first 2 weeks of baseline collection. Therefore, by week 3, all fleet vehicles assigned to the study were instrumented with the IVMS. The recording of speeding, hard braking, and rapid start events began immediately after instrumentation. Minor, moderate, and severe speeding events were not separated within the fleet record of events and thus were combined into one record of events called "Speeding" in this analysis. Lateral acceleration events were not provided with the IVMS event data, and therefore, were not considered in this analysis. Hard braking and rapid start events were combined into one record of events called "Aggressive Driving" in this analysis.

The speeding and aggressive driving events for the anonymous fleet vehicles were provided in the form of hourly rates per week across the baseline and intervention periods. As described above in Table 2, the status of each vehicle was checked for speeding once per minute. Therefore, the maximum event rate would be 60 speeding events per hour. Aggressive driving rates were not scheduled; instead, driving events were triggered any time each vehicle accelerated or decelerated above or below the threshold values listed in Table 2. If an instrumented vehicle was not driven during the week, no data was collected from the vehicle. Due to the anonymous nature of the fleet vehicle data, individual performances were not tracked per driver across weeks.

Participant In-Vehicle Monitoring System Sample

The IVMS vendor provided IVMS speeding and aggressive driving events for the participants who consented to have individual tracking of their events in addition to the collection of naturalistic video and vehicle data. VTTI utilized the route and vehicle data to classify transportation activity, road types, and behavioral driving events.

Subjective Questionnaires

Subjective questionnaires garnered participant feedback about the IVMS. Questionnaires on the IVMS were collected on a sample of five drivers who consented to participate and provide feedback on the systems. As noted, one of these drivers was a replacement participant whose vehicle data could not be used, but that driver's subjective feedback was still usable. The questionnaires requested opinions on the worth of the IVMS before and after the study and ratings of the functionality of the IVMS after the study was completed.

The first subjective questionnaire assessed drivers' attitudes toward the IVMS before the installation of the system and after the completion of the study. Participants were asked to rate a series of items on a continuum in regard to the IVMS. Two examples of different ends of continuums are "ineffective… effective," and "undesirable… desirable."

A second questionnaire, provided to drivers after the study, assessed their perceived effectiveness of the IVMS on real-world outcomes. This questionnaire included items asking drivers to rate how their driving performance changed with the system and how much they would like the system on their vehicle, for example. An example item from this questionnaire is, "How much do you agree with the statement: 'ROVR has made me a safer driver'?" The purpose of these questionnaires was to assess driver acceptance of an IVMS after learning about the system and experiencing it in-vehicle.

Transportation Activity and Schedules

The instrumentation data provided by the IVMS vendor included specific information regarding vehicle trips and participants' driving locations. The vehicle status locations were labeled by the IVMS vendor using third-party maps (e.g., Google Maps) to identify GPS coordinates collected from the vehicle. These specific locations were primarily points of interest (addresses) or roads, with the inclusion of well site names. The specific locations were then classified by the research team as one of the following general locations: Address, Yard, GPS-only (i.e., no label), Highway, Home, Interstate, Location Unavailable (i.e., no GPS), State Route, U.S. Route, or Well (see Table 3).

Table 3. Example of blocked trips from locations labeled home, yard, and well.

Blocked Trip	IVMS Trip	Departure Location	Arrival Location
1 – Commute	1	Home	Address
	2	Address	GPS Only
	3	GPS Only	Well
2 – Commute	1	Yard	Highway
	2	Highway	Address
	3	Address	Home
3 – Site to Site	1	Well	Address
	2	Address	US Route
	3	US Route	Interstate
	4	Interstate	State Route
	5	State Route	Well
4 – Personal	1	Home	Address
	2	Address	US Route
	3	US Route	GPS Only
	4	GPS Only	Home

Blocked trips were created by combining these general locations to summarize driver transportation activity. The blocked trips were organized into the following categories: personal, commute, and site-to-site. These categories were based on departure and arrival location involving home, well, and yard. Other locations (e.g., U.S. route, address) were merged into a block between home, well, or yard arrivals and departures.

Blocked trips classified as personal involved a trip or series of trips that started from a location designated as "home" and ended at a location designated as "home." Blocked trips classified as site-to-site involved a trip or series of trips that started from a location designated as "well" and ended at a location designated as "well." All other blocks were categorized as commute. Table 4 demonstrates the departure and arrival combination decision matrix for trip blocking.

Table 4. Breakdown of blocked trip decision matrix using home, yard, and well locations.

		Arrival Location		
		Home	**Yard**	**Well**
Departure Location	**Home**	Personal	Commute	Commute
	Yard	Commute	Commute	Commute
	Well	Commute	Commute	Site to Site

Driver schedules were created from IVMS date and time data and resulting blocked trips. Schedules were categorized across days as follows: on-duty, off-duty (driving), and off-duty (non-driving). On-duty days contain at least one trip to the yard or a well site. Off-duty (driving) days contain only personal trips made with the fleet vehicle, and off-duty (non-driving) days contain no trips with the fleet vehicle (i.e., no IVMS data). The off-duty (non-driving) days are days without data and exist only between the study collection start and completion dates.

Schedules of on-duty days were also separated among time periods within a 24-hour day as follows: commute time, on-duty time, and off-duty time. Commute times include times from trips within each on-duty day between home to yard, home to well, or yard to well. The reverse trips of well or yard to home in the same day are also included in commute times. On-duty times are all time periods between commute trips in a day. Well-to-well trips, which have been called “site-to-site,” are included in on-duty times. Off-duty times are the times before and after commute trip periods. Some personal trips were judged to occur during on-duty days. These time periods during personal trips were included in off-duty time periods if they were outside the commute periods.

Road Types

Road types were reduced and classified into the following categories: dirt, gravel, paved-unpainted, and paved-painted. To perform this categorization, well sites were mapped into the naturalistic data and classified as dirt road types. Timestamps at the well site were identified, then for each trip that contained a well site, roadways were classified before and after the well site until the participating driver reached a roadway categorized as paved-painted. If the trip ended, the next trip was examined. This created a time-based map of road type data.

Road types were classified visually through video reduction and/or map data. For certain nighttime driving scenarios, it was difficult to obtain road type through video reduction, and classification relied on subsequent map data correlating GPS position. Table 5 demonstrates an example reduction effort of two well site trips to show how road type was classified.

Table 5. Example trips of road type reduction.

Trip #	Road Type	File Sequence	Time Begin (min)	Time End (min)
Trip 1	Paved-painted	1	0	67
	Gravel	1	67	70
	Dirt	1	70	88
	Dirt	2	0	32
	Paved-painted	2	32	74
Trip 2	Paved-painted	1	0	32
	Dirt	1	32	55
	Paved-painted	1	55	87

CHAPTER 3. RESULTS

Data collection via IVMS started in July 2014 and lasted through October 2014. There were approximately 6 weeks of baseline data collection, where the first 2 weeks had fewer drivers than the remainder of the study. Weeks 7–9 consisted of a transition period, during which individuals received the intervention at various times throughout the period. The intervention period took place over weeks 10–16. These weeks and a breakdown of total distance and duration traveled by week are described in Table 6.

Table 6. IVMS data collected by week and study period.

Study Period	Week Number	Number of Vehicles (*n*)	Distance Traveled (miles)	Duration Traveled (minutes)
Baseline	1	7	1,475	2,057
Baseline	2	13	5,375	8,558
Baseline	3	19	11,067	15,782
Baseline	4	21	13,601	19,799
Baseline	5	21	12,188	18,068
Baseline	6	21	12,519	18,369
Transition	7	21	13,779	19,497
Transition	8	21	11,206	17,108
Transition	9	21	12,265	18,500
Intervention	10	20	12,191	17,687
Intervention	11	21	13,519	19,832
Intervention	12	21	12,199	18,749
Intervention	13	21	12,985	19,428
Intervention	14	21	12,309	18,539
Intervention	15	21	11,935	18,006
Intervention	16	20	11,424	17,160

FLEET IN-VEHICLE MONITORING SYSTEM EVENTS

As described in the In-Vehicle Monitoring System section of this report, the IVMS reports vehicle speed every minute after start-up. Speed limits based on the specific road are then applied after recording to these movement events to determine if the individual was speeding at the second mark. Speeding events were classified as minor, moderate, or severe speeding (see Table 2). The IVMS vendor provided the average number of speeding events per hour for each IVMS device (i.e., instrumented vehicle) every week across the fleet, excluding the consented participants' vehicles. Because of the nature of the event collection, drivers could not exceed 60 events per hour. On average, there were 4.61 speeding events per hour (n = 21) across the entire duration of the study.

Further events provided by the fleet consisted of hard braking and rapid start events occurring per hour (see Table 2). These events were combined to create an aggregated score of aggressive driving. The IVMS vendor also provided the average number of events per hour for each IVMS device (i.e., instrumented vehicle) every week across the fleet, excluding the consented participants' vehicles. On average, there were 0.72 aggressive driving events per hour (*n* = 21) across the entire duration of the study.

Speeding

Figure 4 shows the distribution of speeding event rates for all trucks over weeks 2–16 of data collection. The average speeding event rate is also listed for weeks 2–16 of data collection in Table 7. The weeks are labeled with the study period as follows: Baseline, Transition, and Intervention. The plot and table appear to show a decreasing trend in speeding event rate from baseline to intervention.

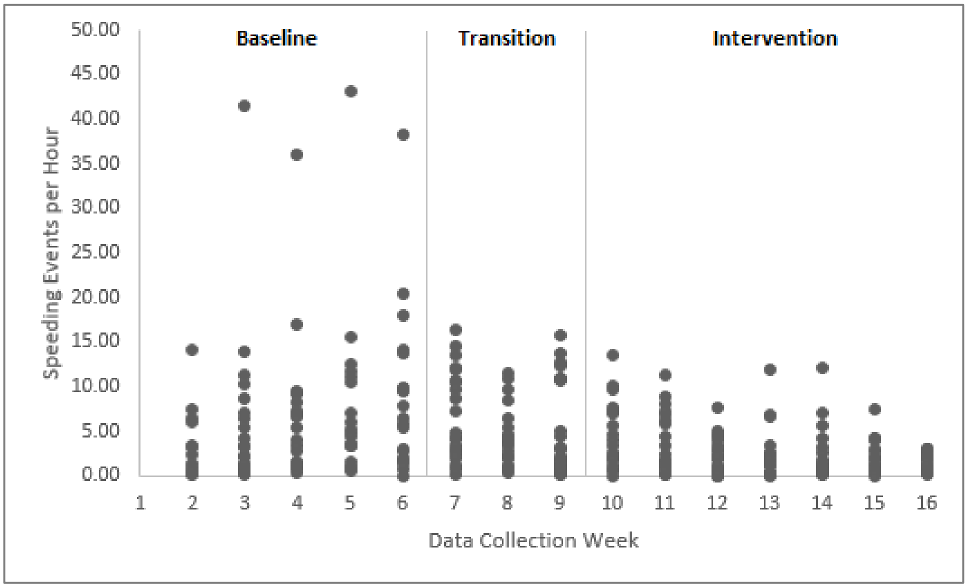

Figure 4. Graph. Speeding events per hour across week.

Table 7. Speeding events per hour by week.

Study Period	Week Number	Speeding Rate Average (SD[a])
Baseline	2	3.60 (4.04)
Baseline	3	6.25 (9.50)
Baseline	4	6.71 (7.87)
Baseline	5	7.22 (9.34)
Baseline	6	8.68 (8.92)
Transition	7	6.87 (5.03)
Transition	8	4.34 (3.31)
Transition	9	5.39 (5.33)
Intervention	10	4.93 (3.72)
Intervention	11	3.61 (3.31)
Intervention	12	2.28 (2.01)
Intervention	13	2.33 (2.93)
Intervention	14	2.13 (2.97)
Intervention	15	1.88 (1.84)
Intervention	16	1.49 (1.01)

[a] SD = standard deviation

The baseline and intervention period were compared for significant differences in speeding event rates using a Wilcoxon signed-rank test. This is a non-parametric test and does not assume the data follow a normal distribution, instead assuming the differences in pairs follow a symmetric distribution. The baseline and intervention periods had a total of 21 matched vehicles. The baseline period had an average of 6.74 speeding events per hour (SD = 8.39), while the intervention period had an average of 2.66 speeding events per hour (SD = 2.85). The intervention was found to have a significantly lower speeding event rate than the baseline period ($W = 6$; $p < 0.0001$).

Aggressive Driving

Figure 5 shows the distribution of the aggressive driving (i.e., hard brake and rapid start) event rate per hour for all trucks over weeks 2–16 of data collection. Table 8 shows the average aggressive driving event rate per hour for weeks 2–16 of data collection. The weeks are labeled with the study period as follows: Baseline, Transition, and Intervention. A visual assessment of the event rate over the weeks of data collection shows a decreasing trend in the aggressive driving event rate from baseline to intervention.

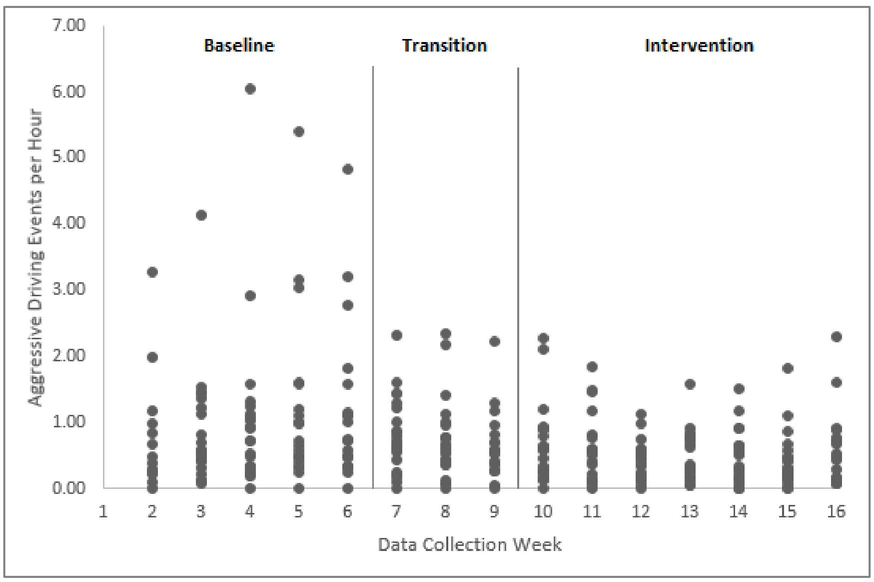

Figure 5. Graph. Aggressive driving events per hour across week.

The baseline and intervention period were also compared for significant differences in aggressive driving using a Wilcoxon signed-rank test. The baseline period had an average of 1.04 aggressive driving events per hour (SD = 1.14), while the intervention period had an average of 0.52 aggressive driving events per hour (SD = 0.47). The intervention period was found to have a significantly lower aggressive driving event rate than the baseline period ($W = 20$; $p < 0.0001$).

Table 8. Aggressive driving event rates per hour by week.

Study Period	Week Number	Aggressive Driving Rate Average (SD)
Baseline	2	0.89 (0.92)
Baseline	3	0.92 (0.92)
Baseline	4	1.05(1.32)
Baseline	5	1.18 (1.27)
Baseline	6	1.14 (1.18)
Transition	7	0.82 (0.58)
Transition	8	0.75 (0.62)
Transition	9	0.63 (0.49)
Intervention	10	0.68 (0.61)
Intervention	11	0.59 (0.52)
Intervention	12	0.43 (0.29)
Intervention	13	0.48 (0.39)
Intervention	14	0.47 (0.41)
Intervention	15	0.41 (0.43)
Intervention	16	0.56 (0.57)

In-Vehicle Monitoring System Discussion

These findings suggest that the IVMS had an improving effect on the fleet's overall safe-driving performance, even though drivers only received feedback on performance through management or emailed reports rather than in real-time in the vehicle. A small number of vehicles were observed to have very high rates of speeding and aggressive driving event rates per hour during the baseline period. The significant reduction in events among those vehicles alone suggests that the IVMSs gave the fleet information they could use to reduce their personnel's risky driving behaviors.

PARTICIPANT IN-VEHICLE MONITORING SYSTEM SAMPLE

Due to the nature of participant data collection, available data were treated as intervention-only, as data collection at this level occurred only after obtaining consent from drivers and therefore after driver awareness of systems. The extent to which coaching occurred from management was not recorded and therefore no changes were expected in driver behavior across time. However, participant evaluations of the IVMS were recorded in the pre- and post- questionnaires.

Questionnaires were completed by five participating drivers. As noted, one driver did not complete IVMS data collection but experienced the IVMS with the other drivers. Questionnaires were analyzed to determine the drivers' opinions regarding the system.

Transportation activity (trips) were provided by the IVMS vendor with departure, vehicle movement status, change of direction, and arrival time and location. The trips were analyzed to determine each driver's trip activity, such as commute, site-to-site, and personal trips. Each driver's work schedule was separated between on-duty, off-duty (driving), and off-duty (no driving) days. The on-duty days were also separated between commute time, on-duty time, and off-duty time to describe each driver's average shift.

Subjective Questionnaires on the In-Vehicle Monitoring System

In Table 9, the pre-test and post-test opinions of the IVMS system are shown by the average ratings given by the five drivers, with rating range. In 9 of the 10 questions, drivers rated the IVMS more positively in the post-test (after using and experiencing the system). In addition, on average, all 10 questions were rated more favorably after gaining experience with the IVMS. Using an independent sample *t*-test, five of the questions had significantly higher averages than neutral: usefulness, favorability, effectiveness, value, and engagement. Also, the overall average for the post-test was significant, suggesting that drivers were generally content with the IVMS and its functions.

Table 9. Participant average attitudinal IVMS ratings.

Item	Scale	Pre-Test Avg. (SD)	Post-Test Avg. (SD)	Difference (Post – Pre)	Difference *t*-test (*p*-value)	Post-test *t*-test (*p*-value)
How much do you like the idea of having ROVR+ on your vehicle?	1: Extremely Dislike – 7: Extremely Like	4.25	4.10	−0.15	−1.50 (0.208)	0.41 (0.704)
Please rate ROVR+ on its: Usefulness	1: Useless – 7: Useful	5.35	5.80	0.45	0.85 (0.441)	4.81 (0.009)*
Please rate ROVR+ on its: Satisfaction	1: Unpleasant – 7: Pleasant	3.85	4.90	1.05	1.95 (0.123)	1.96 (0.121)
Please rate ROVR+ on its: Favorability	1: Bad – 7: Good	4.65	5.80	1.15	1.77 (0.152)	4.43 (0.011)*
Please rate ROVR+ on its: Annoyance	1: Annoying – 7: Nice	3.85	4.50	0.65	1.08 (0.340)	1.12 (0.326)
Please rate ROVR+ on its: Effectiveness	1: Ineffective – 7: Effective	5.35	5.60	0.25	0.38 (0.725)	3.14 (0.035)*
Please rate ROVR+ on its: Likeability	1: Irritating – 7: Likeable	3.65	4.80	1.15	2.31 (0.082)	2.14 (0.099)
Please rate ROVR+ on its: Value	1: Worthless – 7: Assisting	5.25	5.60	0.35	0.74 (0.499)	3.14 (0.035)*
Please rate ROVR+ on its: Desirability	1: Undesirable – 7: Desirable	3.75	4.20	0.45	1.11 (0.330)	0.41 (0.704)
Please rate ROVR+ on its: Engagement	1: Sleep-inducing – 7: Raising Alertness	4.95	5.80	0.85	3.47 (0.026)*	7.06 (0.002)*
Overall	-	4.49	5.11	0.62	2.11 (0.103)	3.84 (0.019)*

*Significant at $\alpha = 0.05$

The difference in driver rating score from the neutral rating was calculated for each question. The average difference, with standard deviation, is included in Table 10. Drivers, on average, gave a positive score in four of the five questions. Independent *t*-tests revealed significance for the item "It would have been useful for the ROVR+ system to alert me about speeding.” This suggests drivers acknowledge the benefit of the IVMS and would like more functionality from the system.

Table 10. Participant average ratings of the IVMS on real-world outcomes.

Item	Scale	Average (SD)	*t*-test (*p*-value)
How does your driving performance with *ROVR+* compare to your driving performance without *ROVR+*?	1: Extremely Worse – 7: Extremely Better	4.80 (0.84)	2.14 (0.099)
How much do you agree with the statement: “I would like to have *ROVR+* in my vehicle?”	1: Strongly Disagree – 7: Strongly Agree	3.80 (1.30)	−0.34 (0.749)
How much do you agree with the statement: “*ROVR+* has made me a safer driver?”	1: Strongly Disagree – 7: Strongly Agree	4.60 (1.14)	1.18 (0.305)
How much do you agree with the statement: “It would have been useful for the *ROVR+* system to alert me about speeding?”	1: Strongly Disagree – 7: Strongly Agree	5.60 (1.14)	3.14 (0.035)*
How much do you agree with the statement: “*ROVR+* is easy to use?”	1: Strongly Disagree – 7: Strongly Agree	5.20 (1.10)	2.45 (0.070)
Overall	-	4.80 (0.65)	2.76 (0.051)

*Significant at $\alpha = 0.05$

Questionnaire Discussion

Driver opinions remained neutral to positive after the study was completed. Drivers also rated the functionality of the IVMS positively. One question in particular provides specific guidance to the IVMS vendor on future development of the system. The rating regarding a question about how useful drivers thought it would be to receive IVMS speeding alerts was rated as significantly positive. This suggests drivers acknowledge the benefit of the IVMS and would like more functionality, such as real-time alerts, from the system.

Transportation Activity

In total, the IVMS provided data from 3,206 trips among the four participant drivers. A breakdown of these trips in distance and duration is provided in Table 11. There was a total of 45,025 miles driven across 61,608 minutes between the start and end of the study collection for the participating drivers.

Table 11. Distance (miles) and duration (minutes) of trips by driver.

	Participant				Overall
	21023	21037	21101	21102	
Total Duration	12,613	17,435	19,953	11,607	**61,608**
Max Trip Duration	89	105	154	191	**191**
Average Trip Duration	19	17	25	16	**19**
StdDev Trip Duration	23	19	30	26	**25**
Total Miles	9,863	12,726	14,167	8,269	**45,025**
Max Trip Miles	82	114	123	173	**173**
Average Trip Miles	15	12	18	11	**14**
StdDev Trip Miles	22	21	27	26	**24**

Work Schedule

In understanding oil and gas workers' behaviors on the road, it is necessary to understand their duties and schedules. Days on which the participant drove to either the yard location or the well are referred to as "on-duty." The remainder of the days are categorized as either "off-duty driving" or "off-duty no-driving" days, depending on collected IVMS data. Table 12 details the work schedule by days for each of the four participant drivers.

Table 12. Driver schedules.

		Participant			
		21023	21037	21101	21102
Driver Schedule	**On-Duty Days**	75 (76%)	59 (60%)	82 (83%)	56 (57%)
	Off-Duty Days-No Driving	16 (16%)	25 (25%)	13 (13%)	11 (11%)
	Off-Duty Days-Driving	8 (8%)	15 (15%)	4 (4%)	32 (32%)

On-Duty Days Schedule

Among the days that the participating drivers were on-duty, the hours that drivers were completing site tasks and the hours that drivers were off-duty, either resting or doing personal activities, can be determined by the periods of time surrounding their commuting hours (see Table 13).

The average on-duty hours for the three drivers (12.51 hours per day) who were tool pushers (foremen) or crew were very different from the fleet safety manager's (participant 21102) average on-duty hours (8.7 hours per day). The same was true for the tool pusher or crew drivers' average daily commute hours (2.85 hours per day) compared to the fleet safety manager's average commute hours (1.79 hours per day). The fleet safety manager occasionally made trips to well sites; however, the manager's usual commute was between home and the yard site. Looking at the combined average daily on-duty and commute times (15.36 hours) among the three tool-pusher/crew drivers demonstrates the long hours that these well servicing workers put in.

Table 13. Driver average daily shift hours.

		Participant			
		21023	**21037**	**21101**	**21102**
On-Duty Days	**Days**	75	59	82	56
	Off-Duty Hours	8.1	9.4	8.5	13.5
	On-Duty Hours	13.6	11.9	12.0	8.7
	Commute Hours	2.3	2.7	3.5	1.8
	Total Working Hours	15.9	14.6	15.5	10.5

The percentages of the average daily hours commuting, on-duty, and off-duty for the foremen/crew drivers are available in Figure 6. The percentages of the average daily hours commuting, on-duty, and off-duty for the safety manager are available in Figure 7.

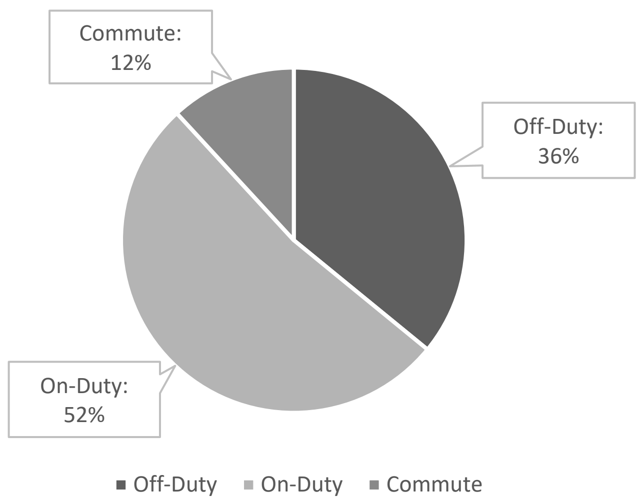

Figure 6. Graph. Average daily percentage of time commuting, on-duty service, and off-duty across tool-pusher and crew drivers.

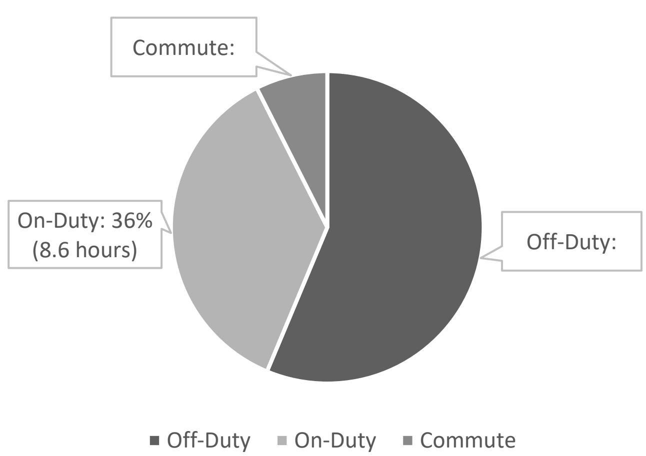

Figure 7. Graph. Average daily percentage of time commuting, on-duty service, and off-duty for safety manager.

On-Duty Days, Vehicle Activity Distribution

Another way of looking at these workers' activity is to focus on their average driving trips specifically when on-duty. The three tool-pusher/crew drivers commuted an average distance of 58.9 miles per trip. Additionally, the average one-way distance and duration to a well site from their yard or home was 75.5 miles and 90.2 minutes, respectively. Drivers also drove between well sites, averaging 4.2 miles per trip. Additionally, drivers occasionally used their assigned fleet vehicle to make personal trips during on-duty days (see Table 14). The distribution of commute, site-to-site, and personal total trip miles per driver is available in Figure 8. A majority of vehicle use occurred during the commute for all drivers.

Table 14. Driver on-duty days vehicle use: distance (miles) and duration (minutes).

		Participant				Overall
		21023	21037	21101	21102	
Commute	**Average Distance**	54.1	61.3	61.4	20.3	**46.3**
	Average Duration	64.2	69.2	81.0	28.3	**57.8**
	Total Distance	9,303	9,682	13,135	5,391	**37,512**
	Total Duration	11,043	10,939	17,333	7,522	**46,837**
On-Duty Site-to-Site	**Average Distance**	2.6	3.9	4.4	25.5	**4.2**
	Average Duration	7.4	11.3	12.0	37.5	**11.1**
	Total Distance	489	1,520	773	432	**3,216**
	Total Duration	1,382	4,424	2,108	637	**8,551**
Personal	**Average Distance**	4.4	31.8	28.6	19.1	**20.9**
	Average Duration	11.8	45.6	56.9	26.8	**30.8**
	Total Distance	70	1,273	257	2,441	**4,042**
	Total Duration	188	1,823	512	3,428	**5,951**

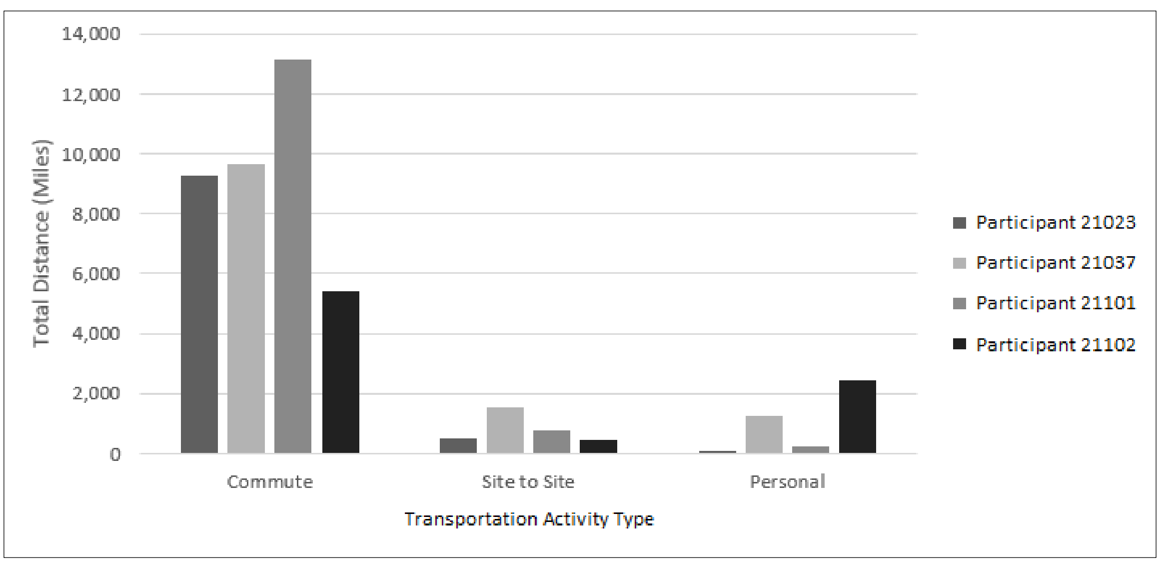

Figure 8. Graph. Vehicle use in total trip miles per driver.

Off-Duty Days, Vehicle Activity Summary

The well servicing drivers also drove their assigned fleet vehicles on off-duty days. A summary of the average trip distance and duration is provided in Table 15. The role of the well servicing drivers would not necessarily influence the personal use of their vehicles. This summary is provided to highlight the use of the fleet vehicles for trips that were not necessarily focused on well-site or yard destinations.

Table 15. Driver off-duty days vehicle use: distance (miles) and duration (minutes)

		Participant			
		21023	**21037**	**21101**	**21102**
Off-Duty Driving Days	**Average Distance**	17.0	58.5	48.6	12.7
	Average Duration	23.4	82.5	57.9	20.4
	Total Distance	101.2	609.0	234.0	584.8
	Total Duration	163	756	330	811

Driving-related Behaviors

Driving behaviors were also examined among participant drivers. Speeding behaviors were measured as they were in the fleet-level analysis. Further, safety-critical events were examined; however, standard trigger processing revealed excessive triggered events due to off-highway situations where the road was uneven or damaged (182,541 steering triggers). Rather than use these triggers, aggressive driving maneuvers were examined using the triggers from the IVMS.

Speed Behaviors, Road Type Summary

Speed behaviors were calculated and sorted into 5-mph bins when travelling at or above 5 mph. Table 16 provides a breakdown of the speed behaviors across all participants on the total collection as well as by different road types. Road types were created from roads traveled as identified by the IVMS. Further reduction was conducted on roads surrounding well sites that drivers visited. Times were labeled in which drivers transitioned between road types, thus classifying all travelled roadways into dirt, gravel, paved-unpainted, or paved-painted (lane lines present) roadways.

Table 16. Time traveled by driver speed behavior across differing road types.

Speed Behavior	Dirt Travel (min)	Gravel Travel (min)	Paved-unpainted Travel (min)	Paved-painted Travel (min)	Total Time
5–10 mph	345.4	9.5	10.2	856.7	1,221.8
10–15 mph	589.3	13.3	21.7	974.5	1,598.8
15–20 mph	1,346.6	22.0	44.4	1,043.1	2,456.0
20–25 mph	1,743.0	24.5	144.5	1,211.1	3,123.0
25–30 mph	569.1	11.5	198.0	1,438.0	2,216.7
30–35 mph	218.7	5.7	212.2	2,154.6	2,591.2
35–40 mph	1,411.9	22.4	177.5	3,089.7	4,701.4
40–45 mph	18.9	-	23.6	2,316.1	2,358.6
45–50 mph	1.4	-	2.0	3,953.4	3,956.7
50–55 mph	-	-	-	3,304.5	3,304.5
55–60 mph	-	-	-	3,035.7	3,035.7
60–65 mph	-	-	-	4,680.4	4,680.4
65–70 mph	-	-	-	3,530.1	3,530.1
70–75 mph	-	-	-	5,203.4	5,203.4
75–80 mph	-	-	-	6,946.0	6,946.0
80+ mph	-	-	-	332.3	332.3
All Speeds	6,244.2	108.8	834.1	44,069.7	51,526.7

The collective time spent on each road type and speed bin is displayed in Figure 9. The bulk of driving time (86%) occurred on paved-painted roadways, most often during commutes to the well sites. A non-trivial amount of driving (12%) occurred on dirt roads, most often lease roads to access the well sites. A small amount of driving time (2%) occurred on the other road types, gravel and paved-unpainted. These roadways most often served as connectors between lease roads and main roadways.

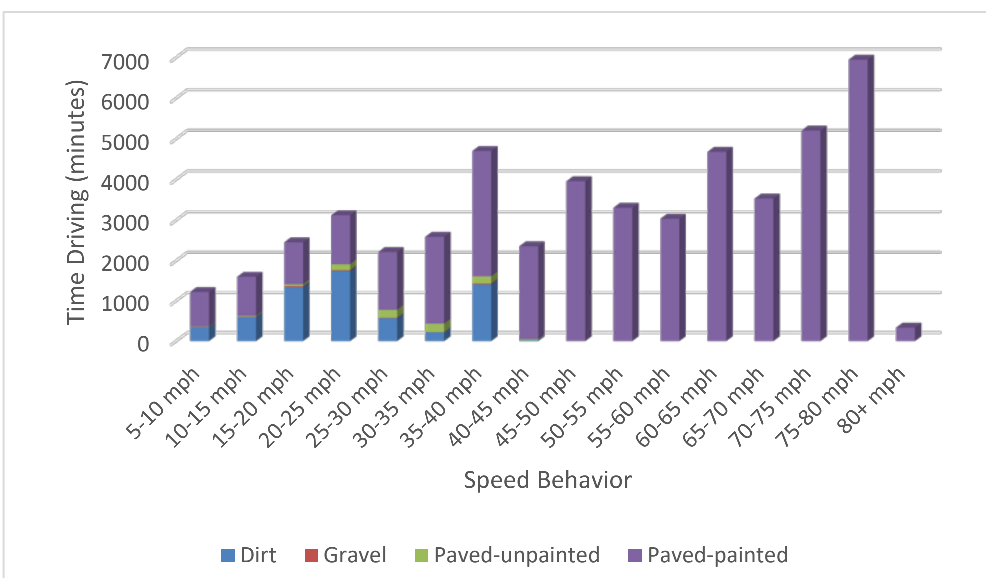

Figure 9. Graph. Total time spent (minutes) across road type and speed behavior.

Speed behaviors were separated by participant driver and are displayed in Table 17. To assess typical well-to-well and commute transportation, speeds below 5 mph were removed, as the time spent at these speeds was typically within-well maneuvering or idle time. No drivers went above 50 mph while on dirt roads.

Most of the time spent on dirt roads was at speeds between 10 mph and 25 mph (59%). However, drivers were at or above 30 mph on dirt roadways for roughly a quarter of the time traveled. Further, participant driver 21101 was responsible for the largest chunk of time driven on dirt roadways (80%).

Table 17. Time traveled for speed behaviors by participant on dirt roadways.

Speed Behavior on Dirt	Time Traveled for 21023 [min (%)]	Time Traveled for 21037 [min (%)]	Time Traveled for 21101 [min (%)]	Time Traveled for 21102 [min (%)]	Total Time Traveled
5–10 mph	12.7 (7.8%)	64.6 (11.9%)	248.3 (5%)	19.8 (3.8%)	345.4 (5.5%)
10–15 mph	20.4 (12.6%)	76.1 (14%)	461.1 (9.2%)	31.7 (6%)	589.3 (9.4%)
15–20 mph	30.9 (19%)	95.6 (17.6%)	1,159.5 (23.1%)	60.6 (11.5%)	1,346.6 (21.6%)
20–25 mph	36.1 (22.2%)	98.3 (18.1%)	1,517.5 (30.3%)	91 (17.3%)	1,743.0 (27.9%)
25–30 mph	19.1 (11.8%)	76.8 (14.1%)	369.7 (7.4%)	103.5 (19.7%)	569.1 (9.1%)
30–35 mph	9.9 (6.1%)	35.4 (6.5%)	82.2 (1.6%)	91.3 (17.4%)	218.7 (3.5%)
35–40 mph	33.2 (20.4%)	96.8 (17.8%)	1,173.2 (23.4%)	108.7 (20.7%)	1,411.9 (22.6%)
40–45 mph	0.1 (0.1%)	0 (0%)	1.1 (0%)	17.8 (3.4%)	18.9 (0.3%)
45–50 mph	0 (0%)	0 (0%)	0 (0%)	1.4 (0.3%)	1.4 (0%)
All Speeds	162.4	543.6	5,012.6	525.8	6,244.4

The proportional breakdown of speed behaviors across drivers is presented in Figure 10. This highlights the extent of speeds captured on dirt roadways. Speed behaviors were distributed similarly across the four participants. Speeds rarely exceeded 40 mph.

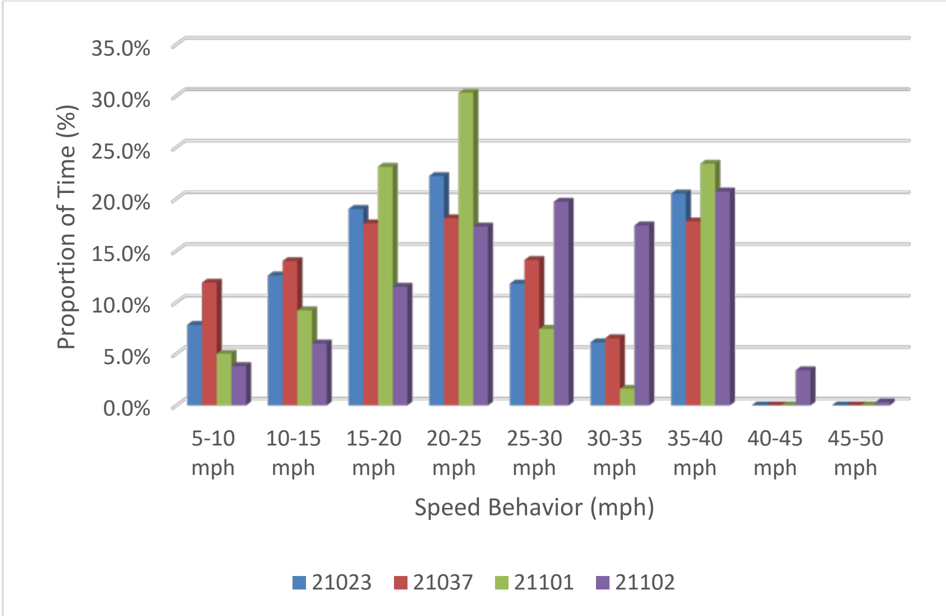

Figure 10. Graph. Proportion of time of speed behavior on dirt roads by participant ID.

Speed behaviors as presented do not account for speed limits. Regarding roadways without posted speed limits, the speed limits on unpaved roadways, private or lease, are often subject to blanket speed limit laws based on state legislation. While Colorado law does not specify a statutory speed limit on unpaved roads (Section 42-4-1101, C.R.S.), similar states have a 25-mph speed limit.

Speeding behaviors on roads with posted speed limits were identified by the IVMS and recorded for the four participant drivers. These behaviors were flagged by the vendor and presented to managers and drivers as feedback for the driver. Speed checks occurred randomly every minute and were compared with the posted speed limit; any speeds greater than 5 mph above the speed limit were flagged for driver feedback. Drivers were ultimately accountable for their speeding behavior while driving and were made aware of their responsibilities as part of the IVMS training.

Although maintaining speed within the speed limits was part of the driver's responsibilities, there were no flagged behaviors nor was feedback provided for speeding behaviors related to roadways without posted speed limits. As such, for the purpose of identifying speeding behaviors on dirt roadways, we classified driving 5 mph above the 25-mph limit as speeding to mirror on-highway speeding behaviors. The summary of speeding behaviors while on dirt and paved-painted roadways is represented in Table 18, including a breakdown by participant drivers.

Table 18. Speed behaviors by road type and participant.

Road Type	Speeding Behavior	21023	21037	21101	21102	Total	Avg	W. Avg
Dirt	Time on Road (min)	162.2	543.6	5,012.60	525.8	**6,244.20**	**-**	**-**
	Speeding (min)	43.2	132.1	1,256.4	219.1	**1,650.8**	-	-
	Speeding (%)	26.6%	24.3%	25.1%	41.7%	**-**	29.4%	**26.4%**
Paved-painted	Time on Road (min)	4,057.2	9,102.9	21,872.2	8,549.9	**43,582.2**	-	-
	Speeding (min)	141.0	440.0	51.0	293.0	**925.0**	-	-
	Speeding (%)	3.48%	4.83%	0.23%	3.43%	**-**	2.99%	**2.12%**
All Roadway	Time on Road (min)	4,219.4	9,646.5	26,884.8	9,075.7	**49,826.4**	-	-
	Speeding (min)	184.2	572.1	1,307.4	512.1	**2,575.8**	-	-
	Speeding (%)	4.4%	5.9%	4.9%	5.6%	**-**	5.20%	**5.17%**

While speeding occurred on merely 2% of paved-painted roadways, driving at or above 30 mph on dirt roadways was much more common (26%) across all four drivers. This may in part be due to drivers being unaware of statutory speed limits, a belief they were driving correctly for conditions, or disregard for IVMS feedback when not being held accountable (i.e., speeds on roads with no posted speed limits). A series of roadway snapshots are displayed in Figure 11, in which participants were driving at speeds equal to or greater than 35 mph while on dirt roadways. This figure shows dirt roadways that are packed and contain a relatively long stretch with minimal obstructed views.

Figure 11. Photos. Examples of dirt roads with driver speed above 35 mph.

In contrast, some unpaved roadways provided challenges and hazards that warranted maintaining slower speeds. Hazards typically seen in the Denver Basin include individually or combinations of:

- Damaged roadways (e.g., potholes, rough terrain)
- Washout/erosion
- Sharp corners
- Unsecure/absent railings
- Thin roadways
- Obstructed views (e.g., shrubbery, mountains)
- Sharp inclines/descents
- Hill crests
- Other vehicles
- Heavy machinery
- Well-related tools/equipment
- Wildlife

To demonstrate rough terrain, a series of roadway snapshots are displayed in Figure 12, in which participants were driving at speeds equal to or less than 10 mph while on dirt roadways. This figure shows dirt roadways that are considered rough terrain, contain sharp curves, or other hazards like vehicles or obstructed views.

Figure 12. Photos. Examples of dirt roads with driver speed below 10 mph.

Higher travel speeds lead to shorter reaction times to roadways that are washed out or damaged, or other conflicts or road hazards. Off-road visual obstructions can be particularly hazardous under certain conditions. Figure 13 displays a series of video stills of an oncoming truck in the middle of the roadway in which the participant driver had to quickly react by maneuvering off-road. The video stills are each 1 second apart, portraying how quickly an event on these roadways can occur.

Figure 13. Photos. Example of visual obstruction and hazard across a 3-second time period.

Hard Braking Maneuvers, Summary

In addition to speeding behaviors, hard braking maneuvers were examined across drivers and road types. Hard braking behaviors were identified by the IVMS and recorded for the four participant drivers. Like speeding events, these behaviors were flagged by the vendor and presented to managers and drivers as feedback for the driver. Results for IVMS hard braking maneuvers are displayed in Table 19, categorized by road type and participant ID.

Table 19. Hard braking events by road type and participant.

Road Type	Hard Braking Maneuver	21023	21037	21101	21102	Total	Avg	W. Avg
Dirt	Time on Road (min)	162.2	543.6	5012.6	525.8	6,244.2	-	-
	Hard Brake Events	0	2	5	0	7	-	-
	Rate per 1,000 Minutes	0.0	3.7	1.0	0.0	-	1.17	1.12
Paved-painted	Time on Road (min)	4,057.2	9,102.9	21,872.2	8,549.9	43,582.2	-	-
	Hard Brake Events	1	27	95	63	186	-	-
	Rate per 1,000 Minutes	0.2	3.0	4.3	7.4	-	3.73	4.27
All Roadway	Time on Road (min)	4,219.4	9,646.5	26,884.8	9,075.7	49,826.4	-	-
	Hard Brake Events	1	29	100	63	193	-	-
	Rate per 1,000 Minutes	0.2	3.0	3.7	6.9	-	3.48	3.87

Further events were identified in which high negative g-forces were present in acceleration data in the naturalistic continuous data. These g-forces recorded peaks above 1 g longitudinal deceleration (i.e., maneuver ≤ -1 g). Results for high negative g-force maneuvers are displayed in Table 20 categorized by road type and participant ID.

Reduction of events from participant 21101 revealed that 100 of the original 101 high negative g-force events were related to driving through a car wash, which triggered events multiple times per wash. These car wash events are excluded from the table. Similar investigations into other drivers did not reveal any systematic situational or behavioral factors such as those identified with participant 21101.

Table 20. High negative g-force maneuvers by road type and participant.

Road Type	Speeding Behavior	21023	21037	21101	21102	Total	Avg	W. Avg
Dirt	Time on Road (min)	162.2	543.6	5,012.6	525.8	6,244.2	-	-
	High Negative g-force Events	1	7	15	1	24	-	-
	Rate per 1,000 Minutes	6.2	12.9	3.0	1.9		5.98	3.84
Paved-painted	Time on Road (min)	4,057.2	9,102.9	21,872.2	8,549.9	43,582.2	-	-
	High Negative g-force Events	6	56	1	23	86	-	-
	Rate per 1,000 Minutes	1.5	6.2	0.0	2.7		2.59	1.97
All Roadway	Time on Road (min)	4,219.4	9,646.5	26,884.8	9,075.7	49,826.4	-	-
	High Negative g-force Events	7	63	16	24	110	-	-
	Rate per 1,000 Minutes	1.7	6.5	0.6	2.6		2.86	2.21

In order to better understand the high g-force events, the average initial speed prior to the brake event was recorded for each driver across road type and is displayed in Table 21. As expected, speeds on dirt roads ranged from 13 to 25 mph. On paved-painted roadways, average speeds by driver hovered between 25 and 60 mph.

Table 21. Average speeds at onset of high negative g-force maneuvers by road type and participant.

Road Type	Negative g-force Maneuver	21023	21037	21101	21102	Total	Avg	W. Avg
Dirt	High Negative g-force Events	1	7	15	1	24	-	-
	Average Speed at Onset (mph)	25.2	13.1	18.4	20.5	-	19.3	17.3
Paved-painted	High Negative g-force Events	6	56	1	23	86	-	-
	Average Speed at Onset (mph)	48.2	60.6	24.8	32.6	-	41.6	51.8
All Roadway	High Negative g-force Events	7	63	16	24	110	-	-
	Average Speed at Onset (mph)	39.0	55.8	18.8	32.1	-	36.4	44.2

Rates of these hard braking maneuvers by participant ID are displayed in Figure 14. Rates are similar between both IVMS hard braking events and high negative g-force events, though the g-force events garnered more events on dirt roadways. This may be due to the combination of hard braking and bumpy road surfaces. For example, Figure 15 displays a video still of the roadway as a participant is performing a hard brake due to a damaged and uneven dirt roadway.

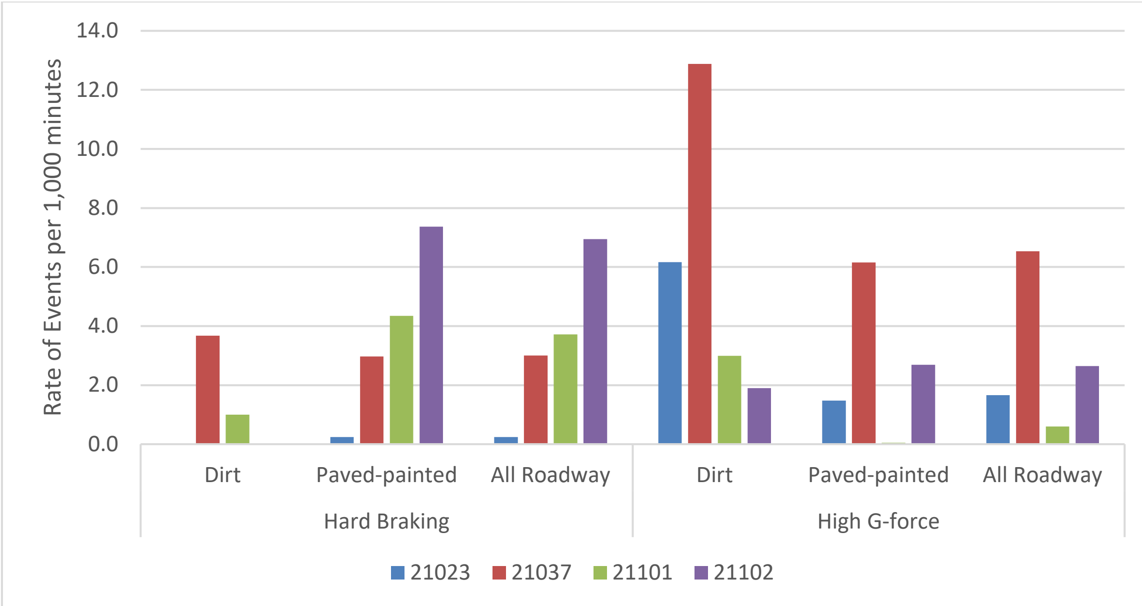

Figure 14. Graph. Rate of hard braking maneuvers by participant ID and road type.

Figure 15. Photo. Example of dirt roadway with high negative g-force maneuver.

CHAPTER 4. CONCLUSIONS

A common sentiment among oil and gas extraction industry representatives is that oil and gas work does not consist of "oil and gas jobs with transportation elements," but rather "transportation jobs with oil and gas elements." The nature of driving in the oil and gas industry reflects exactly that sentiment, with driving representing nearly 3 of the workday's 15 hours. Long hours both on-duty and on-road warrant the industry's extensive examination of oil and gas transportation activities.

Although there are countless jobs in the oil and gas industry with transportation elements, the well servicing technicians observed in this study are representative of the typical worker when it comes to driving. First, workers commute to the well site, then perform various work on the rig, and finally return home. The primary difference in occupational work relates to the efforts and time spent at and on the rigs. As such, well servicing technicians' transportation-related problems are likely systemic for other occupational well workers.

This pilot project demonstrated the utility of IVMSs and the naturalistic data they recorded. By examining a small number of individuals' daily driving styles and habits, along with route-related information, a wealth of data was made available for use in identifying solutions to future industry issues. The unique aspects of oil and gas workers' roles—namely, their transportation activities and related roadway information—can be obtained and utilized as a useful tool for specialized industry questions.

While IVMSs typically provide driver feedback on unsafe driving behaviors, there are still transportation elements in the industry that need to be addressed. As noted in Bell et al., (2017), IVMSs may have no impact on driving behaviors without the implementation of proper coaching. To this end, implementation of IVMSs requires accountability on the drivers' part if the desire is to see behavioral change while in transit. Without these elements, IVMSs essentially function only as GPS-tracking devices. Further, oil and gas fleets should target a positive change in safety culture when implementing IVMSs. The elements not typically addressed by IVMSs, such as distraction or fatigue, can be addressed through changes in safety culture and complementary support systems (Cooper, 2000; Wachter & Yorio, 2014). IVMSs are a useful tool that, if used properly, can start a positive, fleet-wide push for safety.

Onshore oil and gas industry workers have many unique driving activity experiences compared with other occupational drivers, as identified throughout this study. Long work hours combined with extensive off-road driving, all while performing job functions with other hazards, require high amounts of continuous vigilance. Oftentimes such vigilance cannot be maintained to the extent required, and workers may sacrifice vigilance during the daily commute, as this type of driving is more habitual in nature. Continual efforts are needed within the industry to ensure oil and gas workers maintain safe habits both on- and off-site.

REFERENCES

Bell, J. L., Taylor, M. A., Chen, G.-X., Kirk, R. D., & Leatherman, E. R. (2017). Evaluation of an in-vehicle monitoring system (IVMS) to reduce risky driving behaviors in commercial drivers: Comparison of in-cab warning lights and supervisory coaching with videos of driving behavior. *Journal of Safety Research, 60*, 125–136. https://doi.org/10.1016/j.jsr.2016.12.008

Cooper, M. D. (2000). Towards a model of safety culture. *Safety Science*, *36*(2), 111–136. https://doi.org/10.1016/S0925-7535(00)00035-7

Lincoln, J. M., O'Connor, M. B., Retzer, K. D., Hill, R. D., Teske, T. D., Woodward, C. C., … Conway, G. A. (2013). Occupational fatalities in Alaska: Two decades of progress, 1990-1999 and 2000-2009. *Journal of Safety Research, 44*, 105-110.

Mason, K. L., Retzer, K. D., Hill, R., & Lincoln, J. M. (2015). Occupational fatalities during the oil and gas boom—United States, 2003–2013. *MMWR. Morbidity and mortality weekly report, 64*(20), 551.

Retzer, K., & Hill, R. (2011). Fatal injuries in the US upstream oil and gas extraction industry, 2003–2008. *Well Servicing Magazine*, Sep/Oct, 8-21.

Retzer, K. D., Hill, R. D., & Pratt, S. G. (2013). Motor vehicle fatalities among oil and gas extraction workers. *Accident Analysis & Prevention, 51*, 168-174.

Wachter, J. K., & Yorio, P. L. (2014). A system of safety management practices and worker engagement for reducing and preventing accidents: An empirical and theoretical investigation. *Accident Analysis & Prevention, 68,* 117–130. https://doi.org/10.1016/j.aap.2013.07.029