Commercial Motor Vehicle (CMV) Driver Restart Study: Final Report

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

March 2017

FOREWORD

The Federal Motor Carrier Safety Administration (FMCSA) awarded a contract to conduct a naturalistic study of the operational, safety, health, and fatigue impacts of the two restart provisions (i.e., the requirement for two nighttime periods [1–5 a.m.] during a 34-hour restart, and the requirement for a minimum of 168 hours between the beginning of a 34-hour restart period and the beginning of the previous 34-hour restart period—see Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations) on commercial motor vehicle (CMV) drivers. This naturalistic study included a sample of drivers large enough to produce statistically significant results. The study compared the effects of different recovery times using both an in-subject and between-subject research design. It was expected that the two groups of drivers operating under the two restart conditions would overlap, and consequently a paired study design was used to take advantage of its statistical power. This report documents the methods, data analyses, results, and conclusions involved in successfully conducting this study and evaluating the data.

NOTICE

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16. Abstract
A congressionally-mandated naturalistic study was conducted to evaluate the operational, safety, fatigue, and health impacts of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations. A total of 235 commercial motor vehicle drivers representative of the industry contributed data while working their normal schedules, with 181 drivers completing all 5 months of the study. Drivers were monitored via electronic logging devices to track driving and working hours; onboard monitoring systems to detect safety-critical events; wrist actigraph devices for sleep-wake tracking; and smartphone apps for self-ratings of fatigue, sleepiness, stress, sleep quality, and caffeine intake, as well as Brief Psychomotor Vigilance Test (PVT-B) performance testing. Drivers provided 26,964 days of data (17,628 duty days and 9,336 restart days). A total of 3,287 restart/duty cycle sampling units were analyzed. Statistical comparisons were performed using linear and non-linear mixed-effects modeling designed to ensure results were free of selection bias. An analysis of the safety-critical event data did not identify any differences in performance. Drivers' fatigue ratings were higher, and sleep quality ratings were lower, during 1-night versus 2-night restarts [Section 395.3(c)]. Drivers averaged slower PVT-B response times and more PVT-B lapses during restarts after 168 hours than prior to 168 hours [Section 395.3(d)]. During restarts, drivers obtained significantly more sleep (on average, 2 hours more per day), and rated their sleep quality higher and their stress lower as compared to duty days, regardless of provision use. Results indicate that restarts serve to mitigate driver fatigue, stress, and sleep loss (i.e., the restart effectively provides the functional equivalent of a "week end" to recover from fatigue and sleep loss).

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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume (volumes greater than 1,000L shall be shown in m^3)		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
Ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8c+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
app	application
AVECLOS	mean percent eye closure
BMI	body mass index
CCMTA	Canadian Council of Motor Transport Administrators
CDC	Centers for Disease Control and Prevention
CDL	commercial driver's license
CFR	Code of Federal Regulations
CMV	commercial motor vehicle
DF	degrees of freedom
DHS	Department of Homeland Security
ELD	electronic logging device
FAST	Fatigue Avoidance Scheduling Tool
FMCSA	Federal Motor Carrier Safety Administration
FMP	Fatigue Management Program
FMT	Fatigue Management Technology
FS	fatigue scale
GIS	geographic information system
GPS	global positioning system
HOS	hours of service
ICF	informed consent form
ID	identification
IRB	Institutional Review Board
KSS	Karolinska Sleepiness Scale
LTL	less-than-truckload

Acronym	Definition
mph	miles per hour
N/A	not available
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NR	non-restart or duty period
NSBRI	National Space Biomedical Research Institute
OBMS	onboard monitoring system
OIG	Office of Inspector General
ORD	Observer Rating of Drowsiness
OSA	obstructive sleep apnea
PERCLOS	percentage of eye closure
PP	predicted probabilities
PVT	Psychomotor Vigilance Test
PVT-B	Brief Psychomotor Vigilance Test
R	restart period
R1	1-night restart
R2	2-night restart
>R2	more-than-2-night restart
REML	restricted maximum likelihood
RT	reaction time
SAS	Statistical Analysis Software
SCE	safety-critical event
SS	stress scale
SU	sampling unit
T&E	train and engine

Acronym	Definition
The Act	Consolidated and Further Continuing Appropriations Act, 2015
TL	truckload
USDOT	U.S. Department of Transportation
USC	U.S. Code
UTC	Coordinated Universal Time
VTTI	Virginia Tech Transportation Institute

EXECUTIVE SUMMARY

Section 133(c) of the Consolidated and Further Continuing Appropriations Act, 2015 (Public Law 113-235) enacted on December 16, 2014 ("The Act") requires the Secretary of the U.S. Department of Transportation (USDOT) to conduct a naturalistic study of the operational, safety, health, and fatigue impacts of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, on commercial motor vehicle (CMV) drivers.[1]

The hours of service (HOS) regulations in effect until June 30, 2013, prescribed the following:

- Drivers may drive up to 11 hours within a 14-hour non-extendable window after coming on duty following 10 consecutive hours off duty.
- Drivers may not drive after accumulating 60 hours on-duty time (includes driving time and any other work such as loading and unloading the vehicle) in a period of 7 consecutive days (60-hour rule) or 70 hours of on-duty time in 8 consecutive days (70-hour rule).
- Drivers may restart their calculations under the 60/70-hour rule (i.e., the weekly duty cycle) after taking a restart break of 34 or more consecutive hours off duty (commonly referred to as the 34-hour restart rule).

Under the new restart rule that went into effect on July 1, 2013, if CMV drivers choose to use a 34-hour "restart" of the 60- or 70-hour duty-cycle limit, they are required to include at least two nighttime periods—defined as periods from 1 a.m. until 5 a.m. (based on the time zone for their home terminal)—in their restart breaks. Use of the 34-hour restart is limited to once every 168 hours—at least 168 hours must separate the beginning of a restart period and the beginning of the previous restart period.

As required by statute, and over a period lasting as long as 5 months, this study compared operational (work- and sleep-related), safety, fatigue, and health outcomes among CMV drivers operating under a restart period with 1, 2, or more than 2 nights. The study also analyzed the safety and fatigue effects on those drivers who had less than 168 hours between their restart periods and those drivers who had at least 168 hours between their restart periods. The Act temporarily suspended the enforcement of the rules until the Secretary submits the final study report to Congress.

This report details the methods and results of a naturalistic study of the operational, safety, health, and fatigue impacts of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, on CMV drivers. Participating drivers from a diverse range of trucking operations, types, and locations worked their normal schedules and performed their normal duties, for a period lasting as long as 5 months, while being continuously monitored via:

- Electronic logging devices (ELDs) to track hours of service (HOS).
- Onboard monitoring systems (OBMSs) to detect safety-critical events (SCEs).
- Wrist actigraph devices to monitor sleep-wake timing.

- Smartphone-based apps for self-ratings of fatigue, sleepiness, stress, caffeine intake, and performance of the Brief Psychomotor Vigilance Test (PVT-B) of alertness.

A total of 235 CMV drivers enrolled in the study and provided data; 181 drivers finished all 5 months of data collection. This number was sufficient to detect with adequate statistical power relatively small differences in operational, safety, health, and fatigue outcomes between sampling units varying in provision use. In order to track the manner in which drivers opted to utilize the restart provisions, the sampling unit for data analysis was the individual restart/duty cycle. Participating drivers drove a total of 140,671 hours during the study. Drivers contributed a total of 26,964 days of data to the study, including more than 79,000 PVT-B performance tests. Formal statistical comparisons for testing hypotheses concerning differences in expected outcome on the basis of provision use were performed using linear and non-linear mixed-effects modeling. This reduced potential bias and confounding arising from the observational naturalistic study design and accounted for correlations among multiple outcomes from the same driver and among multiple outcomes observed within the same sampling unit.

The mixed-effects model results revealed that use of the 1-night restart option versus the 2-night restart option in Section 395.3(c) had some effects on the study outcomes. When comparing a 1-night restart to a 2-night restart, drivers rated themselves as more fatigued during the 1-night restarts, and their sleep quality was lower during the 1-night restart than during the 2-night restart. However, their sleep quality ratings did not differ during duty periods following a 1-night or 2-night restart. Within-driver analyses focusing on those drivers who used both provision options in each of the two provisions confirmed some of the key findings from the mixed-effects model. Drivers also averaged slower PVT-B response times and more PVT-B lapses during restarts that occurred after 168 hours than during restarts that occurred in less than 168 hours [Section 395.3(d)].

A poolability analysis was used to evaluate whether restart provision effects were consistent across subsets of the trucking operations represented in the study. These results indicated that, in general, industry diversity, relative to carrier size, operations, and segment, did not differ in the use of the provisions or their effects on different outcome domains.

The most robust finding from the study was the increase in sleep time of approximately 2 hours per 24 hours obtained during restart periods compared to duty days. The study provided evidence that drivers were in need of sleep when they undertook a restart, and when they slept during restart they slept much longer than when they were working. Regardless of the restart provision used (i.e., having 34 consecutive hours off duty [Section 395.3(c)] and/or restarting in at least 168 hours [Section 395.3(d)]), there was evidence that the restart periods benefitted the ability of drivers to recover from fatigue and sleep loss.

The research team conducted the naturalistic field study from March to September, 2015. As required by statute, the study compared operational (work- and sleep-related), safety, fatigue, and health outcomes among CMV drivers operating under restart periods with 1, 2, or more than 2 nights. The study also analyzed the safety and fatigue effects on those drivers who had less than 168 hours between their restart periods and those drivers who had at least 168 hours between their restart periods. The sample included drivers from fleets of various sizes (small, medium, and large) and operations (long-haul, regional, and short-haul) in various sectors of the industry (flat-bed, refrigerated, tank, and dry-van) to the extent practicable, to enhance generalizability of the study results.

Table 1 describes the study's statutory requirements and the actions taken to meet them. Page numbers in brackets direct readers to corresponding sections within this report.

Table 1. Study compliance with statutory requirements.

Statutory Requirement/Section	Actions Taken to Successfully Meet Requirement
1. Initiate a naturalistic study of the operational, safety, health, and fatigue impacts of the two restart provisions. **[Sec. 133(c)]**	FMCSA initiated and completed a naturalistic study of drivers who used one or both of the two restart provisions. Data were collected on the time of day and day of week when drivers operated their vehicles, fatigue levels, safety performance, and amounts of sleep and stress. [pp. 19–31]
2. Compare the work schedules and assess operator fatigue between the two groups of drivers (i.e., drivers who take a 2-night [or more] rest period and drivers who take a 1-night rest period). **[Sec. 133(c)(1); Sec. 133 (c)(4)]**	Electronic logging devices (ELDs) generated detailed data on driver schedules, including on-duty and drive time. Data were also collected on driver fatigue levels. The levels of operator fatigue were compared between the different duty cycles. [p. 30]
3. Compare 5-month work schedules and assess safety-critical events (or SCEs, which include crashes, near-crashes, and crash-relevant conflicts) and operator fatigue between the two groups of drivers. **[Sec. 133(c)(2)]**	Each driver was provided a 5-month period to contribute data. Onboard monitoring systems (OBMSs) were used to capture and record SCEs. Primary statistical testing involved within-subjects and between-subjects comparisons. [pp. 25–26]
4. A statistically significant sample should be comprised of drivers from fleets of all sizes, including long-haul, regional, and short-haul operations in various sectors of the industry, including flat-bed, refrigerated, tank, and dry-van, to the extent practicable. **[Sec. 133(c)(2)]**	The Office of Inspector General (OIG) concluded that "…the study plan included a sufficient number of participating drivers to produce statistically significant results." Drivers were recruited from a wide variety of fleet sizes and operation types, making the sample representative of the industry to the extent practicable. [pp. 33–42]
5. Assess drivers' SCEs, driver fatigue and levels of alertness, and driver health outcomes by using both electronic and captured record of duty status, including PVT, e-logging data, actigraph devices and cameras that record SCEs and driver alertness. **[Sec. 133(c)(3)]**	The study utilized state-of-the-art tools to collect data on SCEs, driver fatigue, and health outcomes including OBMSs, ELDs, Brief Psychomotor Vigilance Tests (PVT-Bs), actigraph devices, and smartphone-based daily activity logs and self-reports.
6. Utilize data from ELDs. **[Sec. 133(c)(4)]**	Each vehicle in the study was equipped with an ELD. [p. 30]
7. Initial study plan and final report subject to an independent peer review by a panel of individuals with relevant medical and scientific expertise. **[Sec. 133(c)(5)]**	An independent panel reviewed the initial study plan and the final report, both of which reflect the panel's comments. [pp. 99–108, Appendices F−H]
8. Study to contain a sufficient number of participating drivers to produce statistically significant results. **[Sec. 133(d)(1)(A)]**	The study met the statistical significance requirement with 235 drivers (181 drivers finished all 5 months of data collection) who contributed 3,287 restarts for analysis. [pp. 99–104, Appendices F−G]
9. Use reliable technologies to assess operational, safety, and fatigue components of the study. **[Sec. 133(d)(1)(B)]**	OIG concluded that "…the study plan identified reliable technologies to produce consistent and valid results when assessing operational, safety, fatigue, and health impacts."
10. Use appropriate performance measures to properly evaluate the study outcomes. **[Sec. 133(d)(1)(C)]**	Data were collected on driver demographics and health-related factors, hours of driving and time of day, SCEs, sleep duration, behavioral alertness (PVT-B), and stress measures to assess differences in driver duty cycles. OIG concluded that "the study plan outlined appropriate performance measures to evaluate study outcomes."
11. An appropriate selection of the independent peer review panel. **[Sec. 133(d)]**	OIG concluded that "FMCSA selected individuals with relevant medical and scientific expertise to form an independent peer review panel."
12. Submit work plan to OIG by February 14, 2015. **[Sec. 133(d)]**	Study work plan was submitted to OIG on February 12, 2015, and later posted on the USDOT/FMCSA Web site. OIG briefed Committee staff on March 16, 2015.
13. Submit final report and Department recommendations to OIG. **[Sec. 133(e)]**	The final report and Department recommendations were submitted to the OIG on January 5, 2017.

The study assessed work-related and sleep-related operational factors, drivers' SCEs (crashes, near-crashes, and other safety events), fatigue, driver stress estimates, and driver sleep duration and quality using the technologies specified in the statute. During the study, drivers were monitored for up to 5 months, permitting up to 32 duty cycles (observational periods), each of which constituted a unique sampling unit for analysis. In the design stage, it was expected that drivers would contribute up to 22 duty cycles; however, 32 duty cycles were observed, as the ELDs recorded restart periods that occurred more frequently than every 7 days. Each sampling unit was defined to include the restart period and the duty or non-restart period. This field evaluation oversampled CMV drivers who were more likely to have at least one type of each restart condition. The study team recruited CMV drivers who indicated they routinely drove duty cycles that involved one of the two restart provisions.

The 235 drivers who contributed data for analysis provided a total of:

- 26,964 days of data:
  - 17,628 duty days.
  - 9,336 restart days.
- 3,287 restarts for data analyses:
  - 1-night restarts observed = 426.
  - 2-night restarts observed = 1,577.
  - More-than-2-night restarts observed = 1,284.
  - Restarts taken in less than 168 hours = 1,482.
  - Restarts taken in at least 168 hours = 1,592.

The protocol and consent form for this observational study were approved by an Institutional Review Board (IRB). Drivers were compensated for completing the study measurements.

STUDY DESIGN AND PROCEDURES

Prior to data collection, participants were given a detailed explanation of the study procedures and the informed consent process. The study team provided each participant a study-programmed smartphone, a wrist actigraph device, and training on how to operate the devices. Throughout the study, members of the study team communicated telephonically with drivers on an as-needed basis regarding the condition of the equipment and data transmission capability. Study team members also conducted telephonic weekly scheduled debriefs with drivers to clarify any temporally misaligned data; to allow drivers to ask questions; and to provide feedback to drivers regarding any missing data, study equipment problems, or variations in study procedures.

Participants used a custom smartphone data collection app every day throughout the 5 months of data collection. Table 2 shows the points in time during the participant's duty period when specific measures on the smartphone app were completed.

Participants also used the app during restart days to provide the same measures at a time within 2 hours of waking, about midway through the wakeful period, and within 2 hours prior to sleeping. The app detected motion and did not allow participants to complete the smartphone-based PVT-B while the vehicle was in motion. For team drivers, the study team provided instructions to the off-duty driver in the sleeper berth to complete assessments at the same time as his or her driving partner before the drive, after the drive, and when taking a break.

Table 2. Measures completed by participants on the smartphone app during their duty periods.

Duty Period	Measures Completed
Measures completed on a smartphone (approximately 10 minutes), at the beginning of a duty period before driving.	• Driver completed sleep/wake/duty diary. • Driver performed a Brief Psychomotor Vigilance Test (PVT-B). • Driver rated fatigue on a Fatigue Scale (FS). • Driver rated sleepiness on the Karolinska Sleepiness Scale (KSS).
Measures completed on a smartphone (approximately 5 minutes), during a break from driving, about halfway through a duty period.	• Driver performed a PVT-B. • Driver rated stress on a stress scale (SS). • Driver rated fatigue on the FS. • Driver rated difficulty of drive. • Driver rated degree of drive hazards. • Driver rated sleepiness on the KSS.
Measures completed on a smartphone (approximately 10 minutes), at the end of a duty period after driving.	• Driver performed a PVT-B. • Driver rated fatigue on the FS. • Driver rated sleepiness on the KSS. • Driver completed sleep/wake/duty diary.

ELD data were collected using a variety of approaches based on the carrier's deployed ELD solution. In cases where a carrier did not have an ELD solution, a smartphone-based ELD solution was provided during the study. Drivers' SCEs were captured using camera-based OBMSs. Each OBMS unit was installed in a location that did not impede the driver's view of the forward roadway and was mounted so that it would provide a good view of the forward roadway and the driver (from the driver's lap to the top of the driver's head), thereby allowing data analysts to code fatigue and/or engagement in any non-driving tasks (e.g., texting, eating, etc.).

STATISTICAL ANALYSES

Formal statistical comparisons, including testing of the primary and secondary hypotheses concerning differences in expected outcome on the basis of provision use, were performed using linear(2,3) and non-linear(4) mixed-effects modeling. These analyses were performed using the Statistical Analysis Software (SAS)/STAT® procedures MIXED and GLIMMIX (version 9.4), respectively. The objectives of using the mixed modeling approach were to reduce potential bias and confounding arising from the observational naturalistic study design and to account for correlations among multiple outcomes from the same driver and among multiple outcomes observed within the same sampling unit. As a consequence of being a naturalistic study, drivers self-selected the restart conditions which are the subject of this study. Therefore, adequate handling of selection bias was essential in order to provide for valid inference. Selection bias was addressed in several ways. It was recognized at the design stage that having drivers serve as their own control would be an effective way to minimize selection bias. Notwithstanding the within-driver design features, some drivers were, in fact, not observed under both provision conditions for particular comparisons. Therefore, a statistical modeling approach was employed to address residual selection bias. These approaches are presented in detail in Section 4.7 of this report.

Every model included a factor for the number of nights included in the restart period (1 night versus 2 nights versus more than 2 nights), use of the 168-hour provision, and a factor for restart nights by 168-hour provision interaction. Models also included a set of *a priori* selected covariates specified in the approved study plan. These covariates included age and body mass index (BMI) as continuous variables and the following baseline categorical variables: prior participation in a fatigue management program, gender, marital status, diabetes, high blood pressure, insomnia, sleep apnea, pain experience, use of caffeine, and use of tobacco. Models also included two factors obtained prior to each restart period. These factors related to drivers' planned number of restart nights on their next restart and the reason for this decision. Finally, models for outcomes collected multiple times per day included a time-of-day factor defined according to home terminal time:

- 12 a.m. (midnight) to 3:59 a.m.
- 4 a.m. to 7:59 a.m.
- 8 a.m. to 11:59 a.m.
- 12 p.m. (noon) to 3:59 p.m.
- 4 p.m. to 7:59 p.m.
- 8 p.m. to 11:59 p.m.

Using the covariates described above, estimated predicted mean values for type of provision use were weighted to reflect the characteristics in the obtained sample. Random effects were included in the mixed linear models to account for correlations among outcomes from the same driver and to account for any 'extra' correlation among multiple observations within the same sampling unit for outcomes assessed multiple times. Linear mixed models were used for all continuous and ordinal outcomes. Generalized mixed-effects models were used for outcomes expressed as counts or rates. Details regarding the construction of the mixed-effects models are provided in Appendix K.

RESULTS: KEY OUTCOMES

Table 3 highlights the key findings from data analyses of the four outcome areas. More detailed analyses for each outcome area are presented after this table.

Table 3. Sample of key findings for the research domains examined in this study.

Domain	Research Questions	Study Findings
Operational	Do drivers using the 1-night restart provision have longer work hours per day than drivers using a 2-night restart?	No statistically significant difference.
	Do drivers with <168 hours between restarts have longer work hours per day than drivers with >168 hours between restarts?	No difference, based on the variations among drivers in the shorter periods between the restarts.
Safety	Do drivers using the 1-night restart provision experience a higher safety-critical event (SCE) rate per 100 instrumented hours than drivers who use a 2-night restart?	Not higher.
	Do drivers with <168 hours between restarts experience a higher SCE rate than drivers with >168 hours between restarts?	Not higher, based on the variations among drivers in the shorter periods between the restarts.
Fatigue	Do drivers using the 1-night restart provision have slower psychomotor vigilance responses (lower reciprocal reaction times) on the PVT-B than drivers using a 2-night restart?	Not slower.
	Do drivers with <168 hours between restarts have slower psychomotor vigilance responses (lower reciprocal reaction times) on the PVT-B than drivers with >168 hours between restarts?	Not slower, based on the variations among drivers in the shorter periods between the restarts.
Health	Do drivers using the 1-night restart provision experience increased perceived stress compared to drivers using a 2-night restart?	No significant increase.
	Do drivers with <168 hours between restarts experience increased perceived stress compared to drivers with >168 hours between restarts?	No significant increase, based on the variations among drivers in the shorter periods between the restarts.
	Across all provisions, do drivers sleep more during their restart periods as compared to during their duty cycles?	Yes, ≥2 hours more sleep per 24 hours during restart.
	Across all provisions, do drivers experience more stress during their duty cycles as compared to their restart periods?	Yes, more stress during duty cycle.

Operational Outcomes

To measure the operational impacts of the two restart provisions on CMV drivers, the study team acquired ELD data to determine the number of driving and working hours per day. Table 4 displays the key linear mixed-model operational outcomes in the study. As shown in Table 4, drivers' mean driving hours per 24 hours in duty periods were as follows: 8.22 hours for drivers using a 1-night restart, 8.08 hours for drivers using a 2-night restart, and 8.00 hours for driver using a more-than-2-night restart. The mean driving hours per 24 hours in duty periods for drivers using the 1-night restart were significantly greater than they were for drivers using the more-than-2-night restart (t-value = 2.37, $p = 0.018$). Mean driving hours per 24 hours in duty periods were the same (8.06 hours) for drivers who had less than 168 hours between their restart periods and for drivers who had at least 168 hours between their restart periods.

Drivers' mean work hours per 24 hours in duty periods were as follows: 10.20 hours for drivers using a 1-night restart, 10.11 hours for drivers using a 2-night restart, and 9.98 hours for drivers using a more-than-2-night restart. Mean work hours per 24 hours in duty periods following a 1-night restart were significantly greater than mean work hours per 24 hours in duty periods following a more-than-2-night restart (t-value = 2.30, $p = 0.021$). Mean work hours per 24 hours in duty periods following a 2-night restart were also significantly greater than mean work hours per 24 hours in duty periods following a more-than-2-night restart (t-value = 2.14, p = 0.033). For drivers with less than 168 hours between restart periods, mean work hours per 24 hours in duty periods were 10.11; for drivers with at least 168 hours between restart periods, mean work hours per 24 hours in duty periods were 10.03.

Safety Outcomes

The primary safety outcomes were the rates of SCEs and fatigue-related SCEs per 100 hours instrumented driving time captured via OBMS. These included electronically-recorded hard braking, hard acceleration, swerves, contact with other objects, and driving in excess of posted speed limits. As shown in Table 4 the rates of SCEs per 100 hours instrumented driving time in duty periods were as follows: 0.34 for drivers using a 1-night restart, 0.37 for drivers using a 2-night restart, and 0.35 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the rate of SCEs per 100 hours instrumented driving time in duty periods was 0.36; for drivers with at least 168 hours between restart periods, the rate was 0.37.

The rates of fatigue-related SCEs per 100 hours instrumented driving time in duty periods were as follows: 0.00 for drivers using a 1-night restart, 0.01 for drivers using a 2-night restart, and 0.00 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods and for drivers with at least 168 hours between restart periods, the rate of fatigue-related SCEs per 100 hours instrumented driving time in duty periods was 0.00.

Fatigue Outcomes

Driver fatigue was objectively assessed by measuring driver performance on daily iterations of an electronic PVT-B and subjectively assessed via driver ratings on the KSS. To capture any combined effects of work and sleep on drivers' self-perceptions, drivers also completed a visual-analog FS on a smartphone app.

PVT-B Response Speed

As shown in Table 4 drivers' mean PVT-B response speeds during duty periods were as follows: 3.79 for drivers using a 1-night restart, 3.79 for drivers using a 2-night restart, and 3.77 for drivers using a more-than-2-night restart. The mean PVT-B response speed in duty periods following a 2-night restart was significantly faster (higher number = faster) than in duty periods following a more-than-2-night restart (t-value = 2.57, p = 0.010). For drivers with less than 168 hours between restarts, the mean PVT-B response speed during duty periods was 3.78; for drivers with at least 168 hours between their restart periods, it was 3.77.

Drivers' mean PVT-B response speeds during restart periods were as follows: 3.78 for drivers using a 1-night restart, 3.77 for drivers using a 2-night restart, and 3.73 for drivers using a more-than-2-night restart. The mean PVT-B response speed in 1-night restart periods was significantly faster than it was in more-than-2-night restart periods (t-value = 2.71, p = 0.0067). The mean PVT-B response speed in 2-night restart periods was also significantly greater than it was in more-than-2-night restart periods (t-value = 3.51, $p < 0.001$). For drivers with less than 168 hours between restart periods, the mean PVT-B response speed in restart periods (mean = 3.76) was significantly faster than for those drivers who had at least 168 hours between their restart periods (mean = 3.73, t-value = 2.30, p = 0.021).

PVT-B Performance Lapses

As shown in Table 4, during duty periods, drivers' mean numbers of PVT-B lapses were as follows: 2.97 for drivers using a 1-night restart, 2.90 for drivers using a 2-night restart, and 3.08 for drivers using a more-than-2-night restart. The mean number of PVT-B lapses in duty periods following a 2-night restart was significantly less (fewer lapses = better performance) than the mean number of PVT-B lapses in duty periods following a more-than-2-night restart (t-value = -2.83, p < 0.005). For drivers who had less than 168 hours between restart periods, the mean number of PVT-B lapses in duty periods (mean = 2.94) was significantly less than for those drivers who had at least 168 hours between their restart periods (mean = 3.09, t-value = -2.40, p = 0.017).

Drivers' mean numbers of PVT-B lapses in restart periods were as follows: 3.16 for drivers using a 1-night restart, 3.20 for drivers using a 2-night restart, and 3.59 for drivers using a more-than-2-night restart. The mean number of PVT-B lapses in 1-night restart periods was significantly less than the mean number of PVT-B lapses in more-than-2-night restart periods (t-value = -3.12 p = 0.002). The mean number of PVT-B lapses in 2-nights restart periods was significantly less than the mean number of PVT-B lapses in more-than-2-night restart periods (t-value = -4.71 p < 0.001). For drivers with less than 168 hours between restart periods, the mean number of PVT-B lapses in restart periods (mean = 3.27) was significantly less than for those drivers who had at least 168 hours between their restart periods (mean = 3.48, t-value = -2.63, p = 0.009).

Driver-rated Fatigue on the Fatigue Scale

As shown in Table 4, mean driver-rated fatigue scores on the FS (1 = alert; 5 = tired) in duty periods were as follows: 1.94 for drivers using a 1-night restart, 1.94 for drivers using a 2-night restart, and 1.93 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the mean driver-rated fatigue score on the FS in duty periods was 1.94; for drivers with at least 168 hours between restart periods, it was 1.93.

Mean driver-rated fatigue scores on the FS in restart periods were as follows: 2.01 for drivers using a 1-night restart, 1.95 for drivers using a 2-night restart, and 1.95 for drivers using a more-than-2-night restart. The mean driver-rated fatigue score on the FS in 1-night restart periods was significantly greater than it was in 2-night restart periods (t-value = 1.97 p = 0.049). The mean driver-rated fatigue score on the FS in 1-night restart periods was also significantly greater than it was in more–than-2-night restart periods (t-value = 2.02, p = 0.044). For drivers with less than 168 hours between restart periods, the mean driver-rated fatigue score on the FS in restart periods was 1.96; for drivers with at least 168 hours between restart periods, it was 1.95.

Driver-rated Sleepiness on the KSS

As shown in Table 4, mean driver-rated KSS scores (1 = extremely alert; 9 = extremely sleepy) in duty periods were as follows: 3.46 for drivers using a 1-night restart, 3.47 for drivers using a 2-night restart, and 3.47 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between duty periods, the mean driver-rated KSS score in duty periods was 3.47; for drivers with at least 168 hours between duty periods, it was 3.46.

Mean driver-rated KSS scores in restart periods were as follows: 3.67 for drivers using a 1-night restart, 3.58 for drivers using a 2-night restart, and 3.61 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods and for drivers with at least 168 hours between restart periods, the mean driver-rated KSS score in restart periods was 3.60.

Health Outcomes

The effects of restart schedules on daily sleep duration and driver-rated stress, which are relevant to drivers, were assessed daily throughout the study. Visual-analog SS ratings by drivers were used to assess their perceptions of their stress under each of the restart provisions. There were no statistically reliable differences within duty or restart periods when comparing use of the provisions.

Sleep Duration per 24 Hours

As shown in Table 4, mean sleep duration per 24 hours in duty periods was as follows: 6.48 hours for drivers using a 1-night restart, 6.59 for drivers using a 2-night restart, and 6.59 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the mean sleep duration per 24 hours in duty periods was 6.55 hours; for drivers with at least 168 hours between restart periods, it was 6.58 hours.

Drivers' mean sleep duration per 24 hours in restart periods was as follows: 8.86 hours for drivers using a 1-night restart, 8.83 hours for drivers using a 2-night restart, and 8.32 hours for drivers using a more-than-2-night restart. The mean sleep duration per 24 hours during 1-night restart periods was significantly greater than it was during more-than-2-night restart periods (t-value = 4.48 $p < 0.001$). The mean sleep duration per 24 hours in 2-night restart periods was also significantly greater than it was during more-than-2-night restart periods (t-value = 6.62 $p < 0.001$). For drivers with less than 168 hours between restart periods, the mean sleep duration per 24 hours in restart periods (mean = 8.57 hours) was significantly less than it was for drivers with at least 168 hours between their restart periods (mean = 8.71 hours, t-value = -2.00, $p = 0.046$).

Driver-rated Sleep Quality

As shown in Table 4, mean driver-rated sleep quality (1 = poor sleep quality; 5 = high sleep quality) in duty periods was as follows: 3.75 for drivers using a 1-night restart, 3.79 for drivers using a 2-night restart, and 3.80 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the mean driver-rated sleep quality in duty periods was 3.79; for drivers with at least 168 hours between restart periods, it was 3.80.

Mean driver-rated sleep quality in restart periods was as follows: 3.79 for drivers using a 1-night restart; 3.86 for drivers using a 2-night restart, and 3.87 for drivers using a more-than-2-night restart. The mean driver-rated sleep quality in 1-night restart periods was significantly less than it was during 2-night restart periods (t-value = -2.53, $p = 0.011$). The mean driver-rated sleep quality in 1-night restart periods was also significantly less than it was during more-than-2-night restart periods (t-value = -2.65, $p = 0.008$). For drivers with less than 168 hours between restart periods and for drivers with at least 168 hours between restart periods, the mean driver-rated sleep quality was 3.86.

Driver-rated Stress on the SS

As shown in Table 4, mean driver-rated stress scores on the SS (1 = not stressed; 5 = very stressed) in duty periods were as follows: 1.54 for drivers using a 1-night restart, 1.56 for drivers using a 2-night restart, and 1.58 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods and for drivers with at least 168 hours between restart periods, the mean driver-rated stress score on the SS in duty periods was 1.57.

Mean driver-rated stress scores on the SS in restart periods were as follows: 1.40 for drivers using a 1-night restart, 1.42 for drivers using a 2-night restart, and 1.44 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the mean driver-rated stress score on the SS in restart periods was 1.44; for drivers with at least 168 hours between restart periods, it was 1.42.

Table 4. Overview of linear and non-linear mixed-model outcomes.

Domain	Study Component and Measurement	1-night Restart	2-night Restart	>2-night Restart	34-hour Restart in <168 Hours	34-hour Restart in ≥168 Hours
Operational	Mean driving hours per 24 hours in duty periods	8.22	8.08	8.00	8.06	8.06
	Mean work hours per 24 hours in duty periods	10.20	10.11	9.98	10.11	10.03
Safety	Safety-critical events (SCEs) per 100 hours instrumented driving time in duty periods	0.34	0.37	0.35	0.36	0.37
	Fatigue-related SCEs per 100 hours instrumented driving time in duty periods	0.00	0.01	0.00	0.00	0.00
Fatigue	Mean Brief Psychomotor Vigilance Test (PVT-B) response speed in duty periods (≥3.8 = good performance)	3.79	3.79	3.77	3.78	3.77
	Mean PVT-B response speed in restart periods (≥3.8 = good performance)	3.78	3.77	3.73	3.76	3.73
	Mean PVT-B lapses in duty periods (0 = good performance)	2.97	2.90	3.08	2.94	3.09
	Mean PVT-B lapses in restart periods (0 = good performance)	3.16	3.20	3.59	3.27	3.48
	Mean driver-rated fatigue in duty periods (1 = alert)*	1.94	1.94	1.93	1.94	1.93
	Mean driver-rated fatigue in restart periods (1 = alert)*	2.01	1.95	1.95	1.96	1.95
	Mean driver-rated KSS sleepiness in duty periods (3 = alert)**	3.46	3.47	3.47	3.47	3.46
	Mean driver-rated KSS sleepiness in restart periods (3 = alert)**	3.67	3.58	3.61	3.60	3.60
Health	Mean sleep duration (in hours) per 24 hours in duty periods	6.48	6.59	6.59	6.55	6.58
	Mean sleep duration (in hours) per 24 hours in restart periods	8.86	8.83	8.32	8.57	8.71
	Mean driver-rated sleep quality in duty periods (5 = good)†	3.75	3.79	3.80	3.79	3.80
	Mean driver-rated sleep quality in restart periods (5 = good)†	3.79	3.86	3.87	3.86	3.86
	Mean driver-rated stress in duty periods (1 = no stress)‡	1.54	1.56	1.58	1.57	1.57
	Mean driver-rated stress in restart periods (1 = no stress)‡	1.40	1.42	1.44	1.44	1.42

*Fatigue scale ranges from 1 "alert" to 5 "tired."

**KSS ranges from 1 "extremely alert" to 9 "extremely sleepy."

†Sleep quality scale ranges from 1 "poor sleep quality" to 5 "high sleep quality."

‡Stress scale ranges from 1 "not stressed" to 5 "very stressed."

CONCLUSIONS

This extensive naturalistic investigation yielded both expected and unexpected findings. The use of 1-night, 2-night, and more-than-2-night restarts was expected, as was the additional sleep time the restart afforded drivers for recovery from work fatigue and reduced sleep time when working. The small number of significant effects from the type of restart used for each provision was unexpected. For example, sleep time during duty periods was not different between the two restart provisions. On the other hand, drivers' fatigue ratings were higher during a 1-night restart relative to a 2-night restart and a more-than-2-night restart (statistically reliable differences). Drivers' sleep quality ratings during a 1-night restart were lower than they were during a 2-night restart and a more-than-2-night restart (statistically reliable differences). Although of modest size, these reliable differences were found even when a 1-night restart was compared to the average of all restarts greater than 1 night. This suggests that relative to Section 395.3(c), restarts of 2 or more nights may result in subjectively better quality sleep and less fatigue compared to a 1-night restart. These modest subjective differences in the restart periods had no relationship to fatigue ratings and PVT-B performance during duty periods, which did not vary by how Section 395.3(c) was used.

With regard to Section 395.3(d), restarting in less than 168 hours was associated with faster PVT-B response times and fewer PVT-B lapses of attention during restarts and subsequent duty periods (again, these were modest, but statistically reliable differences). Sleep duration per 24 hours was also longer when the restart was taken at or after 168 hours. These findings suggest that drivers experienced modest, but reliable decreases in behavioral alertness for restarts that occurred at or after 168 hours [Section 395.3(d)].

The slightly elevated subjective fatigue during 1-night restarts [Section 395.3(c)], and the slightly decreased PVT-B performance during restart and duty periods associated with restarts that took place in at least 168 hours [Section 393.5(d)], were consistent with an elevated sleep drive. Consistent with this was evidence that drivers obtained a greater amount of sleep per 24 hours during a 1-night restart compared to a more-than-2-night restart ($p < 0.0001$), and more sleep when restarting at or after 168 hours than when restarting before 168 hours ($p = 0.0457$).

With regard to Section 395.3(d), restarting in less than 168 hours was associated with faster PVT-B response times and fewer PVT-B lapses of attention during both restarts and subsequent duty periods (again, these were modest but statistically reliable differences). Sleep duration per 24 hours was also longer when the restart was taken at or after 168 hours. Together, these findings suggest that drivers experience moderate but reliably greater fatigue associated with 1-night restarts [Section 395.3(c)] and restarts that occur at or after 168 hours [Section 395.3(d)]. Additionally, this fatigue is associated with an elevated sleep drive, as evidenced by the fact that drivers showed a greater amount of sleep per 24 hours during 1-night restart periods compared to more-than-2-night restart periods ($p < 0.0001$), and more sleep when restarting at or after 168 hours than when restarting before 168 hours.

What was profoundly evident in the study results was the markedly increased sleep time afforded by the restarts relative to sleep during work weeks. Sleep time per 24 hours during restart time was increased by over 2 hours from duty time amounts. This kind of differential between sleep duration when working and sleep duration when off duty has also been found in three studies[5,6,7] over the past 10 years that have used actigraphy to track sleep in CMV operators during duty periods and restart or off-duty periods. The consistency of the finding that sleep during duty periods is markedly less than sleep on off-duty days (including restarts) in CMV operators should not be ignored relative to the provisions or to future studies. There is extensive scientific evidence that inadequate sleep is a risk factor for many common health conditions (e.g., obesity, diabetes, and hypertension), as well as errors and crashes.

A recent comprehensive consensus report from a group of scientists from the American Academy of Sleep Medicine and the Sleep Research Society, as well as a report from the Centers for Disease Control and Prevention (CDC), concluded that “insufficient sleep” involves sleeping less than 7 hours per day.[8,9,10] The studies of sleep in CMV drivers, including the extensive data in this study, indicate that drivers obtain 6–6.5 hours of sleep per day for 4–7 days straight (i.e., up to the 168-hour limit), before getting an opportunity to sleep long enough to recover from a sleep debt. There is a need to identify how to increase driver sleep time and avoid the risks that repeated chronic partial sleep loss pose to the health and safety of CMV drivers.

This study provided evidence that drivers were in need of sleep when they undertook a restart, and that when they slept, it was for much longer than when they slept on work/duty days. They were more fatigued ($p = 0.0005$), sleepier ($p < 0.0001$), less behaviorally alert on the PVT-B performance test ($p < 0.0001$), and less stressed ($p < 0.0001$) during restarts. Regardless of the restart provision used (i.e., getting 34 consecutive hours off duty [Section 395.3(c)] and/or restarting in less than 168 hours [Section 395.3(d)]), there was evidence that taking restarts benefitted the ability of drivers to obtain some recovery from cumulative fatigue and chronic sleep restriction. The drivers who participated in the study have made an important contribution to a continued evidenced-based approach to safe CMV driver operations.

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1. INTRODUCTION

The Federal Motor Carrier Safety Administration (FMCSA) hours-of-service (HOS) regulations effective July 1, 2013, for property-carrying commercial motor vehicle (CMV) drivers prescribe that drivers:

- Drivers may drive up to 11 hours within a 14-hour non-extendable window after coming on duty following 10 consecutive hours off duty.
- Drivers may not drive after accumulating 60 hours on-duty time (includes driving time and any other work such as loading and unloading the vehicle) in a period of 7 consecutive days (60-hour rule) or 70 hours of on-duty time in 8 consecutive days (70-hour rule).
- Drivers may restart their calculations under the 60/70-hour rule (i.e., the weekly duty cycle) after taking a restart break of 34 or more consecutive hours off duty (commonly referred to as the 34-hour restart rule).

The regulation requires the 34-hour restart to include two rest periods of 1–5 a.m. Use of the 34-hour restart is limited to once every 168 hours.

The Consolidated and Further Continuing Appropriations Act, 2015 (The Act) directed FMCSA to conduct a CMV Driver Restart Study. Congress directed that within 90 days of enactment of The Act, "…the Secretary shall initiate a naturalistic study of the operational, safety, health, and fatigue impacts of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, on commercial motor vehicle drivers." The FMCSA study required under The Act should compare these impacts in CMV drivers working under the provisions in effect between July 1, 2013, and the day before the date of enactment of The Act (i.e., 2-night restart period), compared to the impacts on drivers working under the provisions in effect on June 30, 2013 (i.e., 1-night restart period) in a sample of drivers large enough to produce statistically significant results. This research project was designed to compare the effects of different recovery times as both a "[with]in-subject and between-subject research design."[i] It was expected that the two groups of drivers operating under the two restart conditions would overlap, and consequently a paired study design was used to take advantage of its statistical power.

1.1 LITERATURE REVIEW SUMMARY

The literature review for recent information pertinent to CMV driver fatigue and recovery times needed between work weeks focused on four domains:

- Recent studies on the need for recovery from fatigue and the effectiveness of the 34-hour restart.

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[i] FMCSA ATTACHMENT A, Statement of Work Commercial Motor Vehicle [CMV] Driver Restart Study, December 18, 2014, p. 2.

- Significant findings from both domestic and international research relating to commercial vehicle driver fatigue.
- Significant findings from the military, Federal Aviation Administration, transit industry, and Federal Railroad Administration (regulations for training railroad engineers) on the effectiveness and measurable safety benefits of an adequate recovery period.
- Health outcomes and sleep among CMV drivers.

Recent findings were examined on:

- Crash risk, breaks, and the 34-hour restart.
- CMV drivers' sleep on work days versus their sleep on off-duty days.
- Human factors and ways to reduce fatigue-related CMV crashes.
- Fatigue management technologies to reduce fatigue-related risks in CMV drivers.
- Fatigue management in other transportation modalities.
- Health outcomes and sleep among CMV drivers.

Studies continue to show that CMV drivers accumulate a sleep debt during duty periods and attempt to pay it off by sleeping longer per 24 hours during restarts and days off duty.[11,12] The latter involves acquiring additional sleep, especially during the biologically programmed nocturnal period for sleep. The literature indicates that fatigue mitigation via work schedules, fatigue management training, and technologies are potentially important avenues for reducing the risk of sleep debt and its consequences for safety and health (obesity-related disorders) in CMV drivers (see References 13, 14, 15, and 16). See Appendix A for the literature review.

The CMV Driver Restart Study contributes to this existing body of knowledge by:

- Providing the most extensive data to date on factors that may contribute to driver safety and fatigue after 34-hour restarts relative to Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations. These measures include safety-critical events (SCEs), which are relevant to crash risk,[17] as well as work time, drive time, sleep-wake timing on work days and restart days, fatigue, sleepiness, stress, driver-reported age, and a variety of self-reported health conditions.
- Demonstrating the importance of cumulative daily duration of sleep obtained during 1-night versus 2-night and more-than-2-night restarts, which aids in determining the extent to which the sleep obtained within each restart provides recovery from fatigue.

1.2 PROJECT SUMMARY

As required by statute, and over a period lasting as long as 5 months, this study compared operational (work- and sleep-related), safety, fatigue, and health outcomes among CMV drivers operating under restart periods with 1, 2, or more than 2 nights. The study also analyzed the safety and fatigue effects on those drivers who had less than 168 hours between the beginning of a restart period and the beginning of the previous 34-hour restart period and those drivers who had at least 168 hours between their restart periods. The sample included drivers from fleets of various sizes (i.e., small, medium, and large) and operations (including long-haul, regional, and short-haul) in various sectors of the industry (including flat-bed, refrigerated, tank, and dry-van) to the extent practicable, to enhance generalizability of the study results. The study assessed work-related and sleep-related operational factors, drivers' SCEs (crashes, near-crashes, and other safety events), fatigue, driver stress estimates, and driver health outcomes by using the following:

- Brief Psychomotor Vigilance Tests (PVT-Bs).
- Electronic logging devices (ELDs).
- Wrist actigraph devices.
- Camera-based onboard monitoring systems (OBMSs).
- Self-administered questionnaires, including:
  - Background survey.
  - Caffeine log.
  - Drive difficulty scale.
  - Drive hazards scale.
  - Fatigue scale (FS).
  - Karolinska Sleepiness Scale (KSS).
  - Sleep diary (sleep onset and offset times).
  - Sleep quality scale.
  - Stress scale (SS).

During this naturalistic field study, drivers were monitored for up to 5 months, permitting up to 32 duty cycles (observational periods) per driver, each of which constituted a unique sampling unit for analysis. In the design stage, it was expected that drivers would contribute up to 22 duty cycles; however, as many as 32 duty cycles were observed for some drivers, as ELDs recorded restart periods that occurred more frequently than every 7 days. Each sampling unit was defined to include the restart period and the duty or non-restart period. This field evaluation oversampled CMV drivers who were more likely to have at least one type of each restart condition. The study team recruited CMV drivers who indicated that they used either or both of the two provisions.

Like other research methods, naturalistic studies can result in participants changing their behavior in a manner they think is desired by the researchers (i.e., demand characteristics), rather than behaving the way they normally would. These studies may also result in people changing behaviors by virtue of their awareness that they are being monitored. Finally, naturalistic studies may have a higher number of volunteer participants who feel they can tolerate the monitoring. They may differ in unknown ways from those who do not want to be monitored in a study, and therefore do not volunteer. These factors may have been present in the study in varying degrees, but every effort was made to provide no guidance to participants as to how they conducted their work-rest activities and schedules. They were assured that their data was treated with strict confidentiality, and the only information provided to them was in relation to study compensation and use of study equipment.

The naturalistic study met the following statutory requirements:

- Used the specified technologies (PVT-Bs, ELDs, wrist actigraph devices, and OBMSs) to measure:
- Operational, safety, health, and fatigue impacts of the two restart provisions.
- SCEs.
- Established an independent peer review panel of individuals with relevant medical and scientific expertise, which:
  - Reviewed the draft study work plan and provided comments.
  - Reviewed the draft final report and provided comments.
- Submitted the study work plan to the Office of Inspector General (OIG).

Table 5 describes the study's statutory requirements and the actions taken to meet them. Page numbers in brackets direct readers to corresponding sections within this report.

Table 5. Study compliance with statutory requirements.

Statutory Requirement	Actions Taken to Meet Requirement Successfully
1. Initiate a naturalistic study of the operational, safety, health, and fatigue impacts of the two restart provisions. [Sec. 133(c)]	FMCSA initiated and completed an observation-based naturalistic study of drivers who used one or both of the two restart provisions. The study met the statistical significance requirement with 235 drivers who contributed 3,287 restarts for analysis. Drivers provided data on 17,628 duty days and 9,336 restart days. Data were collected on the time of day and day of week when drivers operated their vehicles, fatigue levels, safety performance, and amounts of sleep and stress. [pp. 19–31]
2. Compare the work schedules and assess operator fatigue between the two groups of drivers [i.e., drivers who take a 2-night (or more) rest period and drivers who take a 1-night rest period]. [Sec. 133(c)(1); Sec. 133(c)(4)]	Electronic logging devices (ELDs) generated detailed data on driver schedules, including on-duty and drive time. Data were also collected on driver fatigue levels. The levels of operator fatigue were compared between the different duty cycles. [p. 30]
3. Compare 5-month work schedules and assess safety-critical events (SCEs—crashes, near-crashes, and crash-relevant conflicts) and operator fatigue between the two groups of drivers. [Sec. 133(c)(2)]	Each driver was provided a 5-month period to contribute data. Onboard monitoring systems (OBMSs) were used to capture and record SCEs. Primary statistical testing involved within-subjects comparisons (i.e., assessing an individual driver's performance across the different types of restarts taken by that particular driver) and between-subjects comparisons (i.e., comparing the performance of different drivers who took different types of restarts). [p. 25–26]
4. A statistically significant sample should be comprised of drivers from fleets of all sizes, including long-haul, regional, and short-haul operations in various sectors of the industry, including flat-bed, refrigerated, tank, and dry-van, to the extent practicable. [Sec. 133(c)(2)]	The Office of Inspector General (OIG) concluded that "…the study plan included a sufficient number of participating drivers to produce statistically significant results." The study met the statistical significance requirement with 235 drivers who contributed 3,287 restarts for analysis. These drivers were recruited from a wide variety of fleet sizes and operation types, making the sample representative of the industry to the extent practicable. [pp. 33–42]
5. Assess drivers' SCEs, driver fatigue and levels of alertness, and driver health outcomes by using both electronic and captured record of duty status, including PVT-B, e-logging data, actigraph devices, and cameras that record SCEs and driver alertness. [Sec. 133(c)(3)]	The study utilized the following reliable technologies to collect data on SCEs, driver fatigue, and health outcomes: • OBMS • ELD • PVT-B performance test • Wrist actigraphy • Karolinska Sleepiness Scale (KSS) • Stress scale (SS) • Fatigue scale (FS) • Sleep diaries • Caffeine logs • Background survey [pp. 85–86, Appendix B]
6. Utilize data from ELDs. [Sec. 133(c)(4)]	Each vehicle in the study was equipped with an ELD, which collected driver duty status data. [p. 30]
7. Initial study plan and final report subject to an independent peer review by a panel of individuals with relevant medical and scientific expertise. [Sec. 133(c)(5)]	An independent panel reviewed the initial study plan and the final report, both of which reflect the panel's comments. [pp. 99–108, Appendices F−H]

Statutory Requirement	Actions Taken to Meet Requirement Successfully
8. Study to contain a sufficient number of participating drivers to produce statistically significant results. [Sec. 133(d)(1)(A)]	The study met the statistical significance requirement with 235 drivers who contributed 3,287 restarts for analysis. The sampling unit for analysis was the individual restart/duty cycle. Each sampling unit for each participant was categorized as a 1-night restart/duty cycle, a 2-night restart/duty cycle, or a 2-or-more-night restart/duty cycle and as less than 168 hours between restarts or 168 hours or more between restarts. This was reviewed by the independent peer review panel and OIG. OIG concluded that "…the study plan included a sufficient number of participating drivers to produce statistically significant results." [pp. 99–104, Appendices F−G]
9. Use reliable technologies to assess operational, safety, and fatigue components of the study. [Sec. 133(d)(1)(B)]	State-of-the-art technologies (including wrist actigraphs, ELDs, OBMSs, PVT-Bs, and custom smartphone apps) were used to assess the operational, safety, fatigue, and health components of the study. A review of the literature indicates that these technologies are highly reliable and adequately collect data related to the identified measures. Specific products were selected based on a market scan of available technologies. OIG concluded that "…the study plan identified reliable technologies to produce consistent and valid results when assessing operational, safety, fatigue, and health impacts."
10. Use appropriate performance measures to properly evaluate the study outcomes. [Sec. 133(d)(1)(C)]	The study collected data on driver demographics and health-related factors, hours of driving and time of day, SCEs, sleep duration, behavioral alertness (PVT-B), and stress measures to assess differences in driver duty cycles. OIG concluded that "…the study plan outlined appropriate performance measures to evaluate study outcomes."
11. An appropriate selection of the independent peer review panel. [Sec. 133(d)]	FMCSA selected the independent peer review panel based on each individual's scientific and medical expertise. A detailed description of the peer review panel's composition, expertise, and charter was provided to OIG in February of 2015. OIG concluded that "…FMCSA selected individuals with relevant medical and scientific expertise to form an independent peer review panel."
12. Submit work plan to OIG by February 14, 2015. [Sec. 133(d)]	The study work plan was submitted to OIG on February 12, 2015, and later posted on the USDOT/FMCSA Web site: http://www.fmcsa.dot.gov/research-and-analysis/research/new-cmv-driver-restart-study-study-plan. OIG briefed Committee staff on March 16, 2015.
13. Submit final report and Department recommendations to OIG. [Sec. 133(e)]	The final report and Department recommendations were submitted to the OIG on January 5, 2017.

1.3 RESEARCH OBJECTIVES

Project research objectives were focused on using technologies to measure the operational, safety, fatigue, and health impacts relative to CMV driver use of the two restart provisions.

1.4 OPERATIONAL IMPACTS

The measurement of operational impacts consisted of acquiring electronic information on the effects of restart schedule on two major sources of driver fatigue: work and sleep.[18,19] The first domain, operational outcomes (work-related), involved collecting electronic information on the impact of the restart schedule on the demands of driving, relative to four outcomes:

1. Duration of driving per day.
2. Time of day of the drive.
3. Work hours per day.
4. Perceived difficulty of the drive.
5. Perceived degree of drive hazards.

Work-related outcomes 1, 2 and 3 were measured using ELD data, and work-related outcomes 4 and 5 were measured using drivers' visual-analog ratings derived from a smartphone application (app). Sleep-related outcomes were measured using data collected by wrist actigraph devices (actigraph watches), and the sleep diary smartphone app. These tools acquired data on the impact of restart schedule on (recovery) sleep relative to three outcomes:

1. Total sleep time per 24 hours on duty and non-duty days.
2. Subjective sleep quality ratings on duty and non-duty days.
3. Subjective stress ratings on duty days and non-duty days.

1.4.1 Safety Impacts

The primary safety outcomes were the rates of SCEs and fatigue-related SCEs captured via OBMS. These included electronically-recorded hard braking, hard acceleration, swerves, contact with other objects, and driving in excess of posted speed limits. SCEs have been found to increase as a function of time of driving in interaction with time-on-duty of drive.(20)

1.4.2 Fatigue Impacts

Driver fatigue was objectively assessed by measuring driver performance on daily iterations of an electronic PVT-B, which is validated to be sensitive to fatigue from inadequate sleep.(21) Driver sleepiness was subjectively assessed via driver ratings on the KSS, which is validated to be sensitive to sleep loss and sleepiness while driving.(22) PVT-B performance and KSS ratings yielded statistically reliable differences between restart conditions in the original FMCSA HOS Restart Study.(23) False safety triggers, triggered by the OBMS, were also analyzed to identify effects of the restart rule on fatigue-related events. False safety triggers include instances where a trigger threshold was exceeded but there was no safety implication (e.g., the vehicle traveled across train tracks or a pothole and exceeded the kinematic threshold, the driver braked in response to no apparent traffic safety situation, etc.). To capture any combined effects of work and sleep on drivers' self-perceptions, drivers also completed the visual-analog FS and SS on a smartphone app.

1.4.3 Health Impacts

The effects of restart schedules on daily sleep duration and driver-rated stress, which can pose increased risks to health (see Appendix A), were assessed daily throughout the study. In addition, drivers' preexisting health conditions (i.e., obesity, sleep apnea, hypertension, insomnia, diabetes, and pain) were assessed via a background survey (Appendix B) at study entry. Drivers' self-reported health conditions did not have any impact on recruitment selection. Drivers were recruited based on their use of the restart provisions and the other specified recruitment criteria (see Section 3.3.3.). Data from drivers' responses to these questions on the background survey were used as covariates in the analyses.

In addition to the impacts of restricted sleep time on driver alertness/safety, mounting evidence indicates the adverse effects of chronic sleep restriction on health outcomes. Actigraphy evidence has shown that CMV drivers sleep an average of 6.07 hours per 24 hours while in the sleeper berth,(24) and the initial HOS Restart Study confirmed that average daily sleep per 24 hours was 6.0 ± 0.2 hours per 24 hours when there was one nighttime sleep before restart, versus an average of 6.2 ± 0.1 hours per 24 hours when there were at least two nighttime sleeps before restart.(25) Dozens of published biomedical studies indicate the restriction of daily sleep time to less than 6 hours per day results in an increased prevalence and/or risk of the following adverse health outcomes: obesity, diabetes, hypertension, cardiovascular disease, inflammation, pain, and all-cause mortality (see References 26, 27, 28, 29, 30, and 31). Actigraphy and self-reported sleep monitoring of drivers during the study provided evidence on how the use of the provisions relates to daily sleep duration and sleep quality.

Behavioral health refers to maintaining normal emotional and behavioral reactions. Stress, especially chronic stress, erodes behavioral and physical health. Stress leading to burnout in transportation workers has been found to result from reduced and irregular sleep times, resulting in poorer behavioral health and lower job satisfaction.(32,33) The study evaluated the subjective stress levels of study participants under each of the restart provisions using a visual-analog SS. This provided information on the extent to which driver perceptions of stress differed relative to the two restart provisions.

1.4.3.1 Actigraphy that Measures Physiological Metrics

The study team evaluated the publicly-available technologies on the following criteria:

- The reliability and validity of providing physiological health metrics in the trucking environment.
- Time and intrusiveness (burden) on drivers, to ensure the device did not decrease driver recruitment and adherence to the protocols.
- Cost-effectiveness of the device, device implementation, data extraction, and interpretation of data.
- The study team's search of actigraph devices claiming to reliably measure physiological metrics revealed no published scientific evidence of their measurement reliability and validity for medical interpretation; thus, this was not included as a variable in the evaluated products. There was evidence for the validity and reliability of the wrist actigraph device selected for measurement in the study.

2. ASSESSMENT TECHNOLOGIES

As indicated in The Act, the study shall "…assess drivers' safety critical events, fatigue and levels of alertness, and driver health outcomes by using electronic and captured records of duty status, including the Psychomotor Vigilance Test (PVT), e-logging data, wrist actigraphs and cameras or other on-board monitoring systems that record or measure SCEs and driver alertness." ELD devices used in the study shall, to the extent practicable, adhere to "the anticipated requirements for such devices in Section 31137(b) of Title 49, United States Code, from motor carriers and drivers of CMVs, notwithstanding any limitation on the use of such data under Section 31137(e) of Title 49, U.S.C." Table 6 provides a brief summary of each of the assessment technologies used in the study.

Table 6. Summary of assessment technologies used in the study.

Technology	Short Description	What it Measured	Performance Assessment
Onboard monitoring system (OBMS)	An electronic monitoring system with video recorder was installed on the dashboard of each instrumented vehicle. An OBMS event is triggered by certain criteria (e.g., hard braking or swerving). Each event is subsequently reviewed.	• Safety-critical events.	Overall, the OBMS used in the study performed well. There were few issues with the OBMS that resulted in data loss. The 12-second video epoch was a limitation in assessing driver fatigue while driving.
Electronic logging device (ELD)	Device that electronically tracks a driver's on-duty and off-duty driving time for hours-of-service (HOS) monitoring purposes.	• HOS. • Driver duty status.	Overall, there were a few issues with ELDs that resulted in data loss during the study. The total amount of data lost constituted 3.3 percent of the total number of data collection days.
Wrist actigraph	Device similar to a wristwatch that collects movement information while worn and is used to measure sleep/wake patterns.	• Sleep timing. • Sleep quantity.	During the study, there were a few occasions when the actigraph devices did not function properly. The total amount of data lost to actigraph device malfunction constituted 5.5 percent of the total number of data collection days.
Smartphone application (app)	Interactive data collection program installed on a touchscreen mobile phone. The app allows study participants to record sleep/wake times and caffeine use and collects subjective ratings pertaining to fatigue, stress, and difficulty of drive.	• Sleep timing and quantity. • Caffeine consumption. • Perceived fatigue and stress (using fatigue and stress scales). • Perceived difficulty of drive and degree of drive hazards.	During the study, there were 21 instances of a smartphone being lost or damaged. The total amount of data lost to smartphones being lost or damaged constituted 1.4 percent of the total smartphone measures.
Brief Psychomotor Vigilance Test (PVT-B)	Interactive data collection app installed on a smartphone. Each PVT-B lasts 3 minutes and requires drivers to react to triggers that appear on the screen.	Behavioral alertness.	The PVT-B was performed on the smartphone app; see data loss for the smartphone app.

2.1 ONBOARD MONITORING SYSTEMS

The OBMS used in this study was designed to collect the total number of SCEs and fatigue-related events experienced by participating drivers. The latter can only be evaluated using a video-based OBMS, as a kinematic-only OBMS does not allow for the evaluation of fatigue-related events (which can only be accomplished by reviewing the video). Lytx©, which is a major provider of OBMS services (www.lytx.com) and offers the DriveCam Program®, was the OBMS vendor in the study.

2.1.1 Overview of DriveCam Program

The OBMS used in this study had two camera views: a driver face view and a forward-facing view. Figure 1 and Figure 2 show the OBMS and the two camera views captured by the event recorder, respectively. Video was collected at 4 Hz (i.e., one frame of video each 0.25 seconds or four frames of video each second). The OBMS had three accelerometers (y-, x-, and z-axes) that could trigger an event to be recorded. If a forward and/or lateral criterion was met or surpassed (e.g., greater than or equal to $|0.35\ g|$ and $|0.40\ g|$, respectively) the OBMS saved 12 seconds of video (i.e., 8 seconds prior to the criterion being met or surpassed and 4 seconds after). These were the standard thresholds set by the technology vendor for "semi-tractor trailer" vehicles. Triggers included hard brakes, hard accelerations, swerves, contact with other objects, and a speed trigger (described below). There was no discriminating among severity levels for crashes.

The operational definition of a SCE was defined by the technology vendor, and it was not altered in the study (i.e., the technology vendor used its established operational definition for determining if a video epoch[ii] was an SCE). False safety triggers, which are similar to control events or non-events, were also collected in the study. False safety triggers have no relationship to safety, but include instances where a trigger threshold was exceeded (e.g., the vehicle traveled across train tracks or a pothole and exceeded the kinematic threshold, the driver braked in response to no apparent traffic safety situation, etc.). These false safety triggers—which were a secondary outcome variable in this study— were evaluated for visual evidence of driver fatigue (e.g., prolonged eyelid closure, body posture, etc.).

Also available was a speed trigger that recorded video when the vehicle's speed exceeded the posted speed limit by 10 miles per hour (mi/h) or more. The speed trigger used the vehicle's location, as determined by a global positioning system (GPS), and a geographic information system (GIS) overlay to 1) determine the posted speed and 2) compare the posted speed limit to the vehicle's current speed using the GPS information. A speeding event was triggered if the vehicle was traveling 10 mi/h or more over the posted speed limit for 10–15 consecutive seconds. If a driver was traveling continuously above the posted speed limit, the OBMS would initiate approximately three speeding triggers per minute. No prolonged speeding occurred in the study.

[ii] An epoch is 12 seconds long (8 seconds before the trigger threshold is exceeded and 4 seconds after the trigger threshold)

For analysis purposes, only the first speeding trigger in the "speeding event" was a distinct SCE. Speeding triggers that occurred within 60 minutes of each other were filtered. Below are some examples of how the study team filtered the speeding triggers.

- Example with multiple speeding triggers and no duty status change or change in driving behavior:
  - Speeding trigger (SCE), speeding trigger 10 minutes later (discarded), speeding trigger 20 minutes later (discarded), speeding trigger 70 minutes later (SCE).
- Example with multiple speeding triggers and a change in driving behavior:
  - Speeding trigger (SCE), speeding trigger with following too close 10 minutes later (SCE), speeding trigger 20 minutes later (SCE), speeding trigger 5 minutes later (discarded).
- Example with multiple speeding triggers and duty status change:
  - Speeding trigger (SCE), duty status change 15 minutes later (off duty for 15 minutes), speeding trigger 20 minutes later (SCE), speeding trigger 30 minutes later (discarded).

Typically, when a fleet is using the DriveCam program, the OBMS will display a light when the vehicle surpasses this speed threshold, alerting the driver of his or her driving performance. The reduced SCEs are then uploaded to a secure server where safety managers can access the data and coach drivers (where warranted). The OBMS light and safety manager access/coaching were not included in this study.

Figure 1. Image. OBMS and typical installation of OBMS.

Figure 2. Image. Front camera view (left) and driver's face view (right).

2.1.2 Issues Encountered with the Onboard Monitoring Systems

During the study, there were occasions when the OBMS did not function properly (e.g., malfunctioning OBMS, object blocking the OBMS cameras, etc.). If the technology vendor could not repair these issues remotely, the problems were communicated to the research team and addressed as soon as possible using situation-appropriate solutions, such as replacing the OBMS or contacting the driver and requesting that he/she remove an item blocking the cameras. There were also occasions when a driver drove a truck that was not equipped with an OBMS (e.g., truck with an OBMS was being repaired, slip-seat operations, etc.). The time periods when the OBMS was malfunctioning and/or a driver was driving a truck without an OBMS would result in no SCEs being collected, leading to the false assumption that the driver did not have any SCEs. As described in more detail below, the time periods when the OBMS was malfunctioning and/or a driver was driving a truck without an OBMS were removed from the analyses of SCEs.

2.2 ELECTRONIC LOGGING DEVICES

HOS data provided the primary independent variables (1 night versus 2 nights versus more than 2 nights) during the restart period and whether the elapsed time from the initiation of the prior restart to the initiation of the next restart was less than 168 hours or 168 hours or more. From the HOS data, the study team extracted variables related to driver duty status. These data included date- and time-stamped (Coordinated Universal Time [UTC] and converted home terminal time) indicators of when driver status changed to "Driving," "On-duty," "Sleeper," and "Off-duty." When determining status of restart provisions, "Driving" and "On-duty" were collapsed to "Working," and "Off-duty" and "Sleeper" were categorized to "Not Working." Off-duty time can include a variety of non-working activities. These HOS data were collected via ELDs. When possible, the research team used the carrier's existing enterprise-grade ELD solutions, such as Omnitrac or Peoplenet.

Table 7 lists the frequency of ELD products used by drivers in the study.

Table 7. Frequency of ELD systems used by drivers in the study.

ELD Product	Number of Drivers
BigRoad with DashLink	29
JJ Keller	1
Omnitracs	134
Peoplenet	74
Rand McNally	2
XRS	1
Custom ELD solution	1

In cases where a carrier did not have an ELD solution, the BigRoad smartphone app with DashLink© was provided to the driver. The BigRoad smartphone app with DashLink was selected after a review of available technologies on the market. DashLink is fully compliant with 49 U.S.C., Section 395.15. It works in conjunction with the BigRoad mobile app to record driving time, automatically ensuring that driver HOS logs are created accurately. The DashLink device is plugged into the truck's diagnostic port, or otherwise connected to the vehicle's engine, and the BigRoad app is used to configure the vehicle for use in engine-connected mode. HOS data entered through the BigRoad app was automatically transmitted to a centralized BigRoad server and was accessible by the study team.

2.2.1 Issues Encountered with Electronic Logging Devices

Overall, there were few issues with ELD devices that resulted in data loss during the study. However, there were several occasions where the study team was unable to collect ELD data, including the following: driver or carrier refusal; a temporary switch to operations where logs were not required; and driver discontinuation of participation in the study, with a delayed actual withdrawal date due to difficulty reaching the driver. Drivers did not provide ELD for 1,074 days during the data collection period (or 3.3 percent of the total data collection days). Note that data collection days are different than study days.[iii]

2.3 ACTIGRAPHY

Participants wore wrist actigraph devices throughout their time in the study to measure sleep timing and quantity. Actigraphy is a minimally obtrusive, validated approach to assessing sleep/wake patterns. The Actigraph wGT3X-BT, produced by ActiGraph Company (see Figure 3), was selected for use in the study after a review of available technologies. At the time of the study, it was the one cost-effective actigraph technology that could wirelessly transmit

[iii] Ongoing comprehensive quality control checks identified an additional issue regarding the ELD source data subsequent to completion of the analysis. It was determined that for 29 drivers, occasionally only partial ELD data for a specific study day was transmitted. There were a total of 109 study days where this occurred (0.40 percent of all study days). The calculated average duty hours per work day would have only increased by 0.01 hours (48 seconds) with the inclusion of these data. Review of the additional data also indicated one instance (0.03 percent of all sampling units) of a misclassified sampling unit that was designated as a 1-night restart instead of a 2-night restart.

movement data to the smartphone for uplink, along with the drivers' self-reported data and PVT-B performance data, to the investigators. This markedly improved data acquisition timeliness and completeness.

Figure 3. Image. Wrist Actigraph wGT3X-BT, produced by ActiGraph Company.

2.3.1 Issues Encountered with Actigraphy Devices

During the study, there were occasions when the actigraph devices did not function properly. The most common device malfunctions occurred when the battery on the device was fully discharged. When this occurred, devices had to be sent back to the study team to be reconfigured. When actigraph data was not uploaded to the data server via a participant's mobile data link, a member of the study team contacted the study participant to determine the status of the actigraph device. Once the actigraph device was verified to be nonfunctional, the study team couriered a replacement actigraph device to the study participant. In the time between malfunction of the actigraph device and receipt of a replacement actigraph device, participants continued to provide data on all other measures. The total amount of data lost to actigraph device malfunction constituted 1,752 data collection days (or 5.5 percent of the total number of data collection days).

2.4 SMARTPHONE APPS

During the participant briefing session, each participant was assigned an Android smartphone that was used for data collection in the study. This smartphone was enabled with a mobile data plan only (no phone call or texting capability). Three apps were delivered on the smartphones to support data collection:

- A background survey app.
- The BigRoad ELD app (described above and only for those drivers without an enterprise-grade ELD solution).
- The Pulsar custom SleepFit data collection app (described below).

2.4.1 Custom Smartphone Data Collection App

The custom data collection app used in this study was specifically developed to support transportation field studies. This app was used successfully in the 2014 field study evaluating the HOS restart provision.[34] In this study, participants used the app every duty day for up to 5 months to complete the PVT-B, maintain a sleep diary; record caffeine consumption; and submit subjective ratings related to stress (SS), fatigue (FS), difficulty of drive, and degree of drive hazards (see Figure 4).

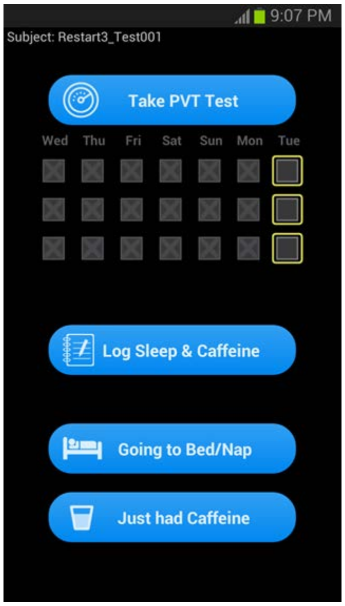

Figure 4. Image. Custom smartphone data collection app.

2.4.1.1 Brief Psychomotor Vigilance Test

The original 10-minute PVT was invented by Dr. David F. Dinges, through support from the U.S. Office of Naval Research. It has been validated to detect slowing of psychomotor speed and lapses of attention,[(35)] as well as vigilance decrements and instability in behavioral alertness,[(36)] which are common adverse effects of fatigue on performance due to inadequate sleep, wakefulness at night, and prolonged time-on-task. The original 10-minute PVT has been validated to be sensitive to fatigue[(37,38,39)] in more than 100 published scientific studies that include a range of experimental, simulated, and some occupational (real-world) evaluations (e.g., transportation operators, health care professionals, and first responders).

Through research supported by the National Space Biomedical Research Institute (NSBRI) via a National Aeronautics and Space Administration (NASA) cooperative agreement, Dr. Dinges and colleagues empirically developed an algorithm for PVT stimulus delivery rate and response quantification that resulted in the briefer 3-minute PVT-B. Using experiments supported by the National Institutes of Health (NIH), NSBRI/NASA, and the Department of Homeland Security (DHS) on the performance effects of total and chronic partial sleep loss in healthy adults, they demonstrated that performance on the 3-minute PVT-B tracked performance on the 10-minute PVT throughout total and partial sleep loss.[(40)] In the past 6 years, the NSBRI and NASA have supported the use of the PVT-B to track the behavioral alertness of 6 participants in a 520-day, high-fidelity simulated mission to Mars,[(41)] and of 24 astronauts before, during, and after 6-month missions on the International Space Station. For the above reasons, the PVT-B was used to provide data on drivers' behavioral alertness on and off duty during the study (see Figure 5).

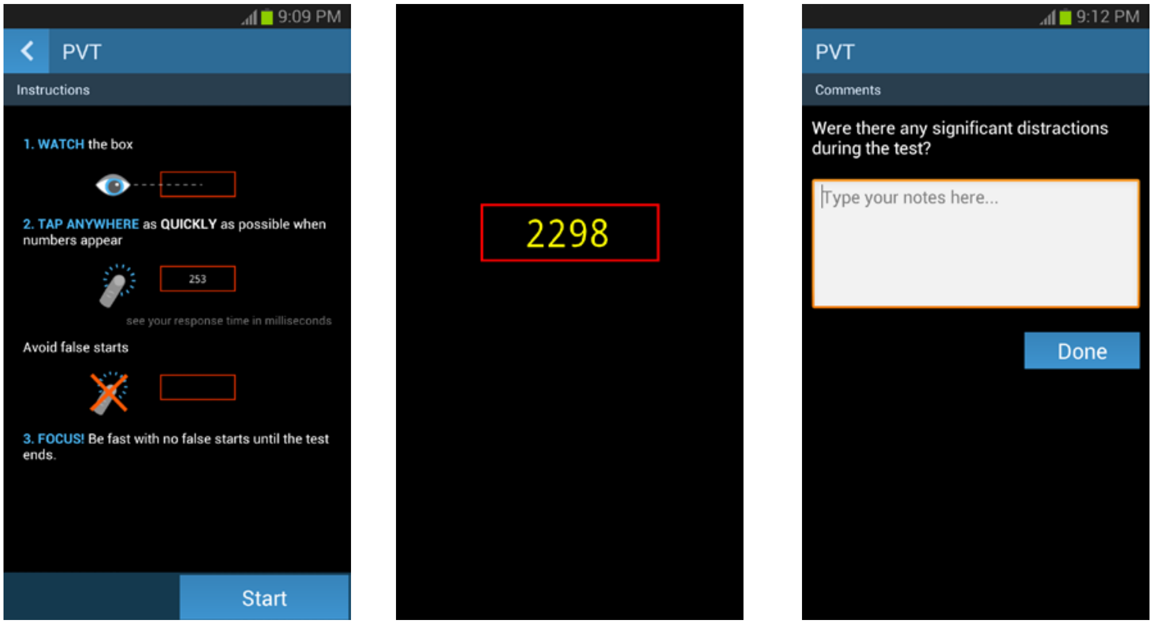

Figure 5. Screenshots. PVT-B performed on the smartphone data collection app.

2.4.1.2 Sleep and Caffeine Logs

In addition to wearing an actigraph device, participants completed a daily sleep diary providing inputs related to sleep timing and self-reported sleep quality (including naps) and caffeine use. The sleep diary aided in interpreting the actigraph data, while providing an opportunity to collect data related to participants' perceptions about their sleep quality and their caffeine consumption (see Figure 6).

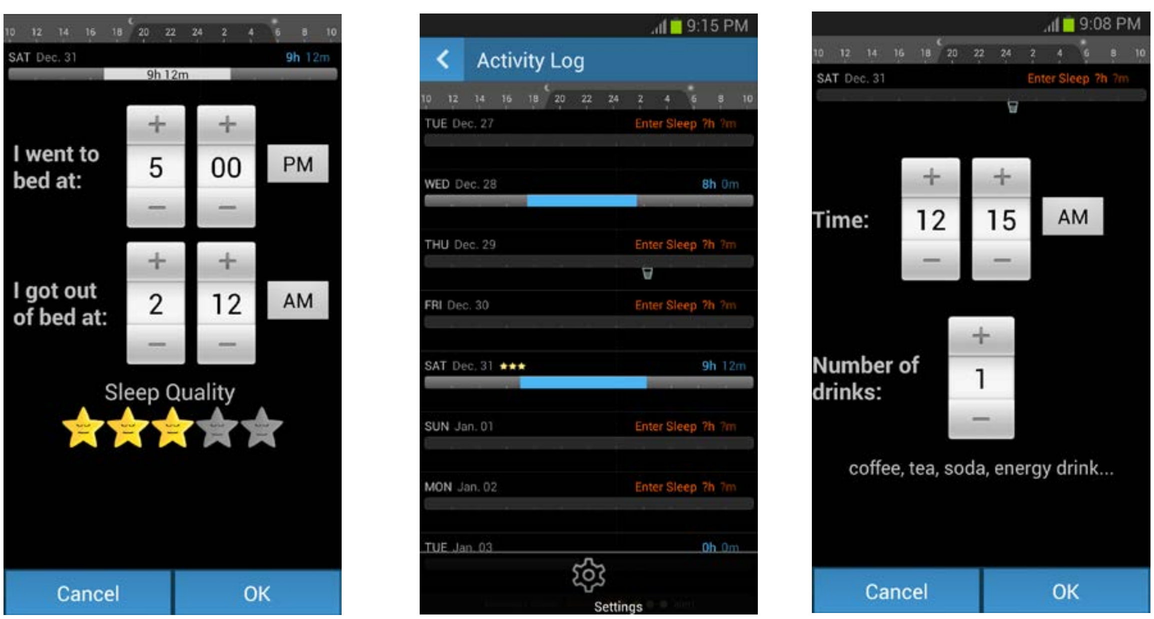

Figure 6. Screenshots. Sleep diary and caffeine log performed on the smartphone data collection app.

2.4.1.3 Karolinska Sleepiness Scale and self-reports related to stress, fatigue, difficulty of drive, and degree of drive hazards

After completing each PVT-B, participants completed the KSS and provided subjective ratings (based on their perceptions) related to their stress level (rated on the SS), fatigue level (rated on the FS), the difficulty of their drive, and safety hazards experienced during their drive. The KSS and the above-listed self-reports of fatigue, stress, difficulty of drive, and safety hazards experienced were used in the 2014 field study on the HOS restart provision.(42) The KSS has been widely used in the literature as a subjective assessment of alertness (see Figure 7). The KSS is a 9-point Likert-type scale ranging from "extremely alert" to "extremely sleepy." The FS is a 5-point scale ranging from "alert" to "tired." The SS is a 5-point scale ranging from "not stressed" to "very stressed." The difficulty of drive scale is a 5-point scale ranging from "easy" to "difficult." The degree of drive hazards scale is a 5-point scale ranging from "few" to "many."

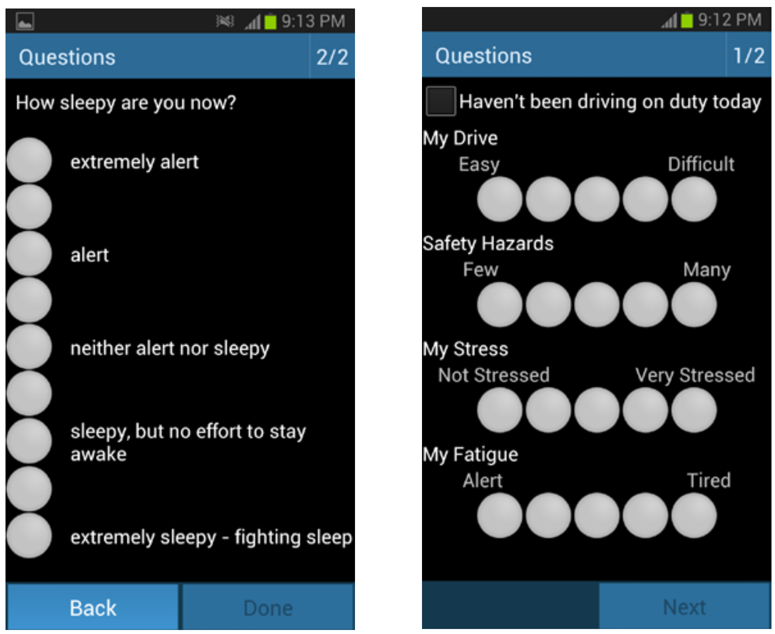

Figure 7. Screenshots. KSS and self-reports related to stress, fatigue, difficulty of drive, and degree of drive hazards, performed on the smartphone data collection app.

2.4.2 Issues Encountered with Smartphone-based Measures

During the study, there were 21 instances of a smartphone being lost or damaged. When smartphone data (i.e., PVT-B, sleep diary, or driver ratings) were not uploaded to the study data server via a participant's mobile data link, a member of the study team contacted the study participant to determine smartphone device status. Once the smartphone was verified to be lost or damaged, the study team couriered a replacement device to the study participant. In the time between damage to or loss of the smartphone and receipt of their replacement smartphone, participants were instructed to provide data on all other available study measures. The total amount of data lost to smartphones being lost or damaged constituted 440 data collection days (or 1.4 percent of the total smart phone measures).

2.4.3 Preexisting Health/Medical Conditions

The background survey questionnaire (Appendix B) was administered to drivers during study enrollment. This questionnaire requested anthropometric measures (i.e., height, weight, and age) and data related to existing health conditions that were used as covariates in the analyses.

3. METHODS AND APPROACH

Below is a description of the procedures and methods used to complete this study. The aim was to provide these methods in chronological order (as they were initiated during this study), but there may be some overlap of activities.

3.1 OVERVIEW

The study used a naturalistic approach—defined as an "unobtrusive observation or observation taking place in a natural setting"[(43)]—to evaluate the impacts of Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations on CMV drivers. Specifically, the potential effects of 1) a 1-night restart relative to a 2-night restart and a more-than-2-night restart and 2) the potential effects of a restart taken in less than 168 hours versus a restart taken in at least 168 hours were evaluated relative to selected operational, safety, health, and fatigue outcomes. The study team enrolled a stratified convenience sample spanning the industry in terms of fleet size (small, medium, and large), type of operation (long-haul, regional, and short-haul), and industry sector (flatbed, refrigerated, tank, and dry-van) to enhance the generalizability of study findings. Participants were observed over the course of 5 months.

3.2 INSTITUTIONAL REVIEW BOARD

As required for all studies involving human subjects, the study team submitted an application to the Virginia Tech Transportation Institute (VTTI) Institutional Review Board (IRB) for their review and approval. The application included the research protocol, which provided a detailed description of all study tasks, data confidentiality, and data access. The application also contained an Informed Consent Form (ICF) to be signed by each participating driver. See Appendix C for one of the four different versions of the ICF (different versions of the ICF were created to account for presence of an ELD, presence of the BigRoad app, and significant travel to an installation site) and the VTTI IRB approval letter. The ICF outlines the study objectives and methods, data confidentiality, any possible risks, compensation, and the rights of the participant (including freedom to withdraw from the study at any time, for any reason). No human subject activities were conducted until IRB approval was received on February 18, 2015 (VTTI IRB# 15-063).

3.3 RECRUITMENT

3.3.1 Sampling Plan

Taking advantage of the within- and between-driver design, a sample size of 199 has 80 percent power to detect a standardized effect size of 0.2 (mean difference divided by the standard deviation of within-driver differences) using a paired t-test with a 0.05 two-sided significance. A standardized effect size equal to 0.2 is typically considered small in the behavioral sciences.[(44)] However, effect sizes of this magnitude still have potentially important public health policy implications when applied to populations. Inclusion criteria were used to enrich the sample with regard to drivers expected to contribute both 1-night restarts and 2-or-more-night restarts.

However, drivers contributing only 2-or-more-night restarts still contribute statistical power to the comparisons in the mixed-model analyses. The target enrollment was specified in the approved study plan as 207 drivers, which is larger than 199. The number of drivers in excess of 199 helps to make up for any loss of power arising from some drivers contributing only more-than-2-night restarts. By the end of the study, 235 drivers had contributed at least 1 sampling unit for analysis. In summary, enough drivers were included in the study to detect with adequate statistical power relatively small differences in outcomes between sampling units varying in provision use.

For the results to be generalizable to the widest range of driving operations, drivers were to be recruited from small, medium, and large carriers involved in short-haul, regional, and long-haul operations on different truck types, including flat-bed, refrigerated, tank, and dry-van *to the extent practicable*. Each of the subgroups was represented to the extent feasible.

Below are the operational definitions for the industry segmentations:

- Carrier size:
  - Small: 1–50 power units.
  - Medium: 51–500 power units.
  - Large: more than 500 power units.
- Type of operation:
  - Short-haul: the driver normally operates within a 100 air-mile radius of the driver's home terminal.
  - Regional: the driver normally operates beyond a 100-air mile radius and up to 250 air-mile radius of the home terminal. The trip normally involves a single day—out and back to the home terminal.
  - Long-haul: the driver normally operates beyond a 250 air-mile radius of the driver's home terminal. The driver operates away from the home terminal for multiple days and the trip involves single or multiple loads.
- Industry sector (definitions used in the Fatality Analysis Reporting System[iv] and General Estimates System[v]):
  - Flat-bed: flat surface above rear tires; may have a front bulkhead and stake or strap accommodations (including car hauler).
  - Refrigerated: a refrigerated and insulated box trailer.
  - Tank: cylindrical for liquid transport (including cement trucks).
  - Dry-van: fully enclosed with hard or soft sides and side and/or rear doors.

[iv] http://www.nhtsa.gov/FARS
[v] http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+(NASS)/NASS+General+Estimates+System

3.3.2 Industry Outreach

The study required recruitment of carriers and individual driver participants from participating carriers. The study team used existing industry contacts to communicate with drivers and trucking companies in an effort to recruit drivers at their respective fleets. This involved sending 1,143 direct emails and making 244 direct phone calls to drivers and carriers. A wide variety of organizations were contacted to solicit their support in recruiting drivers for the study. These included the following organizations:

- Alliance for Driver Safety & Security.
- American Trucking Associations.
- American Transportation Research Institute.
- California Construction Trucking Association.
- California Trucking Association.
- Commercial Vehicle Safety Alliance.
- International Brotherhood of Teamsters.
- National Association of Small Trucking Companies.
- Owner Operator Independent Drivers Association.
- Tennessee Trucking Association.
- Transportation Trades Union.
- Washington State Trucking Association.
- Western Trucking Alliance.
- Women in Trucking.

The study was advertised on the Dave Nemo Open Road Channel Radio Show (every other Monday morning from 9–10 a.m. at Satellite Radio XM 171 or Sirius 147) throughout the recruitment period. The study team also visited the Mid-America Trucking Show in Louisville, KY from March 31 to April 2, 2015.

3.3.3 Carrier Participation

After carriers provided a commitment to support the study, the study team worked closely with senior management and operational personnel to review company HOS data (if available) and/or driver self-report data to identify drivers who met the following criteria:

- Held a valid Class A commercial driver's license (CDL) during the course of participation.
- Worked more than 60 hours per week (at least occasionally).
- Completed drives in the day and night.

- Used 1-night, 2-night, or more-than-2-night restarts and/or took restarts more frequently than 168 hours.

The study team also asked potential participants if they planned on continuing to work under the above conditions. Every effort was made to coordinate with the dispatchers and carrier operational staff to advertise the study to drivers who met the study criteria. In support of driver recruitment, two standardized posters were created (one directed at carriers and one directed at drivers) that provided details about the study (see Appendix D).

3.3.4 Web-based Screening and Enrollment of Drivers

The recruitment efforts described above directed carriers and drivers to the official recruitment Web site (www.RestartStudy.com). The recruitment Web site (see Appendix E for screenshots) provided an overview of the study and an opportunity for drivers to register to be considered as participants. Interested drivers answered several screening questions designed to assess whether carriers/drivers met the study inclusion criteria (as shown above). Drivers were also asked to provide contact information so that the study team could later contact them. A total of 5,176 unique visitors accessed the recruitment Web site—757 of these visitors completed or partially completed the screening questionnaire, and 379 met the study criteria. Ultimately, 242 drivers were empaneled in the study. Table 8 shows the distribution of empaneled drivers across the various industry segmentations.

Table 8. Driver empanelment by industry segmentation.

Industry Segmentation	Target N for Analysis	Drivers Empaneled	Drivers Contributing ≥ One Sample	Carriers
Small	110	47	43	45
Medium	20	76	73	34
Large	77	119	119	16
Total	**207**	**242**	**235**	**95**
Long-haul	95	192	187	90
Regional	56	32	31	8
Short-haul	56	18	17	3
Total	**207**	**242**	**235**	**101***
Dry-van	119	133	130	55
Flat-bed	33	35	35	14
Refrigerated	33	63	59	26
Tank	22	11	11	11
Total	**207**	**242**	**235**	**106***

*A total of 95 different carriers participated in the study. Some carriers provided drivers from more than one industry segment.

3.3.5 Empanelment Logistics

Due to the geographic distribution of participants and varying driver schedules, the process of empaneling drivers and equipping vehicles required a great deal of coordination. To support timely hardware installation and in-person informed consent briefings, the study team offered a variety of empanelment options. Drivers had the option of attending a scheduled vehicle installation and briefing session at 1 of 11 selected technology deployment locations/convenient operational centers. Alternatively, the empanelment team scheduled empanelment trips—on a case-by-case basis—to carriers employing eight or more participants. Finally, seven participants were empaneled on site at the Mid-America Trucking Show.

The technology deployment locations/convenient operational centers used for empanelment purposes during this study included: Allentown, PA; Atlanta, GA; Blacksburg, VA; Freemont, CA; Memphis TN; Ontario, CA; Philadelphia, PA; Riverside, MO; Seattle, WA; and Warrenville, IL.

3.4 DRIVER RETENTION

To maximize participant retention and compliance with study protocols, the study measures were collected in near-real-time and reviewed daily to detect missing, spurious, or corrupt data, or device hardware or software failures. When a protocol deviation was detected (e.g., the OBMS camera lens was obstructed), a member of the study team contacted the participant to understand the source of the problem and to provide corrective feedback. Immediate feedback was essential for ensuring driver compliance with the study protocol throughout the entire data collection phase of the study.

Drivers were reimbursed for their efforts in support of the study. Driver compensation was based on completion rates of study activities on a pro rata basis according to the following schedule. Drivers could receive up to $2,166 if they participated for the entire 5 months of this study, and if they completed all assessments as requested. Participants received three payments over the course of their participation as follows:

- $75 at the initial meeting for signing the ICF and completing the health assessment. This was paid in cash or check at the time of the meeting (if possible), or a check was mailed to the participant’s home within 1 week.
  - $50 for attending the initial briefing and signing up for the study.
  - $25 for completing a health assessment questionnaire during the initial briefing.
- A second payment of up to $1,891 for participating in the study if they contributed data for 5 full months. They received this payment by check mailed to their home within 30 days of completing participation.
  - Up to $1,606 for 22 weeks of participation. Participants were asked to complete three smartphone assessments, three times per day, to receive the following payment:
    - $3 per assessment × three assessments/day = up to $9/day.
    - $9/day × 7 days in a week + $10 bonus for completing all assessments in a week = up to $73/week.
    - 22 weeks × $73/week = $1,606 for completing all assessments.
  - $25 for participating in a debriefing phone call at the end of the study.
  - $260 bonus for completing 5 full months of participation.

- Drivers received a third (and final) payment of up to $200 if they returned all three pieces of equipment. Pre-paid packaging materials were sent to participants at the end of the study. Participants received this payment by check, which was mailed to their home within 30 days of receiving the equipment:
  - $50 for returning the actigraph device.
  - $50 for returning the smartphone.
  - $100 for returning the OBMS.

If a participant elected to withdraw from the study or if their employment ended (and the new employer would not authorize their involvement in the study), that participant was compensated for their participation up to that point.

3.5 PARTICIPANT BRIEFING

3.5.1 Pre-study Briefing

During the pre-study briefing, participants were given a detailed explanation of all of the study procedures and the informed consent process. These pre-study briefings were held at one of the participating carrier's terminal locations, the Mid-America Trucking Show, or at one of the other installation locations across the United States. The following activities took place during the pre-study briefing:

- Participants were asked to confirm that they had a valid CDL.
- Participants were assigned a smartphone and an actigraph device.
- Researchers took a digital photograph of each participant's face to assist with identification when reviewing video data.
- Participants completed the background survey, either on paper or using a researcher's computer.
- Participants completed a W9 tax form for subject reimbursement.
- Participants were trained to use the various smartphone apps (i.e., PVT-B, FS, SS, KSS, caffeine log, difficulty of drive, degree of drive hazards, and sleep diary), the BigRoad app (if their truck did not have an existing enterprise-grade ELD), and how to download the data from their wrist actigraph devices.
- Participants also had the opportunity to ask any questions.

3.5.2 Weekly Debriefs

Throughout the study, members of the study team communicated (by phone and/or email) with drivers on an as-needed basis and during weekly scheduled debriefs. The purpose of this contact was to receive clarifications from drivers regarding misaligned data, to ask questions, and to provide feedback about missing data, study equipment problems, or study procedures that were not followed correctly.

During these weekly debriefs, study participants were also asked to predict their next restart (e.g., 1-night, 2-night, or more-than-2-night restart). The reason for this selection (operational imperative versus driver preference) was also elicited, using the following wording:

1. Largely my decision, but based on work requirements.
2. Largely my decision, but based on personal preference.
3. Largely my company's decision.
4. Largely due to Federal regulations.

This allowed comparisons between driver predictions and actual restart conditions. This was done as a measure of selection bias.

3.5.3 Final Debriefing

The final participant debriefing was scheduled following the 5-month data collection period or when participants exited the study. Participants returned the equipment (smartphone, actigraph device, and OBMS) to the study team via mail using pre-paid packaging. Those drivers who had an existing Lytx OBMS installed in their truck prior to the study did not return the OBMS and automatically received the $100. The study team received final clarifications from drivers regarding data that did not align, asked questions, and provided feedback about missing data, study equipment problems, or study procedures that were not followed correctly. In addition, study participants had an opportunity to ask questions about the study or express any concerns.

3.6 VEHICLE INSTALLATION

The study team equipped participants' vehicles with an OBMS. This installation took place after the participant pre-study briefing. The installation process was fairly easy and took approximately 30–60 minutes. As shown in Figure 1, the OBMS was installed in a location that did not impede the driver's view of the forward roadway. As shown in Figure 2, the OBMS was mounted so that it would provide a good view of the forward roadway and the driver (from the driver's lap to the top of the driver's head), thereby allowing data analysts to code fatigue and/or engagement in any non-driving tasks (e.g., texting, eating, etc.).

3.7 DATA COLLECTION

Once participants signed the ICF, received their assigned study equipment/training on how to use the apps and actigraph devices, and their vehicles were fully installed with the required equipment (OBMS and possibly an ELD), data collection began. Participating drivers drove an instrumented vehicle for up to 5 consecutive months. Below is a description of how the data were collected, reduced, and transmitted.

3.7.1 Onboard Monitoring System Data

The technology vendor was responsible for all OBMS data collection and reduction. The encrypted video and quantitative data from all instrumented trucks were automatically sent to the technology vendor via cellular transmission. The received data were reviewed, reduced (i.e., data analysts marked the presence of specific variables pertaining to each event), and uploaded to a secure server.

3.7.1.1 Data Reduction

Data analysts underwent an extensive 5-week training regimen prior to reducing “real” data. The technology vendor currently sees 97-percent reliability with a 95-percent confidence interval using their standard data reduction protocols. The study team added additional reduction variables, including enhanced fatigue, traffic density, and reaction time to precipitating event. To ensure the additional reduction variables were being reduced correctly, the study team requested that the first 500 events (SCEs and false safety triggers) be reduced by two data analysts and one senior trainer (if necessary, to break any discrepancies between the two data analysts) and that the results be sent to the research team to calculate reliability. At the quarter point of data reduction (25 percent of all events reduced), the study team evaluated reliability on events reviewed by two reductionists. Reliability at both checkpoints was satisfactory; thus, no retraining was required and data reduction commenced as planned. Random reliability checks were also completed on validated events (events that overlapped with the driver’s duty status via the ELD and truck number) by comparing the participating driver’s picture to the video image. These random checks were 100 percent accurate. The technology vendor’s data analysts performed blind data coding, in that they did not know what type of restart each of the participants had taken.

Once the data were received, a trained data analyst reviewed the data to determine if it represented a valid SCE or a false safety trigger (e.g., hitting a pothole in the street, driving on a bumpy road, etc.). False safety triggers, though normally not reduced, received the same reduction as SCEs except for the reaction time to predicating event variable (noted below). Standard data reduction involved reviewing the video and recording the trigger type, outcome, root cause, demeanor, risky behaviors, and adverse weather conditions (if necessary). Additional reduction questions were added in the study, including enhanced fatigue coding, traffic density, and reaction time to precipitating event. The date, time, fleet number, and driver identification (ID) number were automatically tagged to the SCE and false safety trigger. Data analysts completed their reduction of the SCEs and false safety triggers approximately 1–14 days from the time the data were recorded by the OBMS in the instrumented truck and uploaded to the technology vendor’s secure server.

3.7.1.2 Fatigue-coded Safety-critical Events and False Safety Triggers from the Onboard Monitoring System

“Observer rating of drowsiness” (ORD)[vi] is a well-established method for measuring fatigue using video data to assess facial features and body language.[(45)] However, ORD requires at least 1 minute of video and the “average” score over that minute is used to assess fatigue. For example, a driver could show significant signs of fatigue earlier in the video, but appear to be less fatigued later in the video, as it is common for people to drift in and out of fatigue, but

[vi] ORD demonstrated good intra- and inter-rater reliability in that the measure correlated highly (r = +0.7 to 0.9) with eye closure measures such as PERCLOS (percentage of time that the eyes were closed 80 percent or more) and mean percent eye closure (AVECLOS).

remain fatigued overall. In this example, the driver would be coded as showing significant signs of fatigue even though he/she showed periods of lower fatigue in the video.

The video length in this study was 12 seconds, and only the first 8 seconds of video could be used, as the precipitating event (e.g., swerve in response to a lead vehicle stopping or driving over rough road if it was a false safety trigger) could increase the driver's arousal. Thus, ORD was not possible and data analysts at the technology vendor were trained to perform an enhanced analysis of fatigue (conducted on all SCEs and false safety triggers). The length of the video only allowed for a determination of acute fatigue, as less subtle (but common) signs of fatigue could not be determined reliably with 8 seconds of video.

Data analysts were instructed to watch the driver's face and body language in the 8 seconds prior to the trigger threshold during SCEs and false safety triggers. A bivariate measure of fatigue was used given the limited amount of video data. After watching the video data, data analysts employed a rating to record the presence of acute fatigue using the following ratings:

- **Fatigue (but not asleep):** As a driver becomes very fatigued, slow eyelid closures usually occur. This is often accompanied by a rolling upward or sideways movement of the eyes themselves. The individual may also appear not to be focusing the eyes properly, or may exhibit a cross-eyed (lack of proper vergence) look. Facial tone will probably have decreased. Very fatigued drivers may also exhibit a lack of apparent activity, and there may be large isolated (or punctuating) movements, such as providing a large correction to steering or re-orienting the head from a leaning or tilted position. Drivers are close to falling asleep and usually exhibit prolonged eyelid closures and similar prolonged periods of lack of activity. There may be large punctuated movements as they open their eyes.
- **No fatigue:** May exhibit some or none of the signs above; however, the driver did not meet the criteria noted above for fatigue.
- **Asleep:** Drivers are falling asleep if they exhibit prolonged eyelid closures (3 seconds or more). There may be large punctuated movements as they transition in and out of intervals of dozing. A driver cannot be coded as fatigued and asleep.
- **Unknown:** It was too dark to make out the driver's eyes, the view was obscured, or the camera malfunctioned.
- **Not available (or N/A):** A parked vehicle was struck or was being loaded; a driver bumped the camera when parked.

The overall inter-rater reliability (i.e., agreement between the two data analysts) for the enhanced fatigue reduction was 88.3 percent.

3.7.1.3 Traffic Density

All SCEs and false safety trigger events were reviewed by the data analysts to determine traffic density. Traffic density was a qualitative measure used to relate the quality of traffic service (in terms of traffic flow and speed). There were three levels of traffic density: low, medium, and high. Low density was when traffic flowed at or above the posted speed limit and motorists had complete mobility between lanes or maneuverability within the traffic stream was only slightly restricted. Medium density was where the ability to maneuver through lanes was noticeably restricted and lane changes required more driver awareness. Speeds were slightly decreased as traffic volume slightly increased. Freedom to maneuver within the traffic stream was much more limited. High density was when traffic flow became irregular and speed varied rapidly because there were virtually no usable gaps to maneuver in the traffic stream and the speeds rarely reached the posted limit. This also included instances where every vehicle moved in lockstep with the vehicle in front of it, with frequent slowing required (i.e., traffic jam). The overall inter-rater reliability for the traffic density reduction was 85.9 percent.

3.7.1.4 Reaction Time to Precipitating Event

All SCEs were reviewed by the data analysts to determine the driver's reaction time to the precipitating event. A precipitating event was the state of environment or action that began the SCE sequence under analysis. In other words, what environmental state or what action by the subject vehicle, another vehicle, person, animal, or non-fixed object was critical to this vehicle becoming involved in the SCE. The driver's reaction to the precipitating event was when the driver was first seen to recognize and begin to react to the SCE occurring. The number of frames (each frame is 0.25 seconds) between the precipitating event and the driver's reaction to the precipitating event was used to determine the driver's reaction time. No reduction was performed on SCEs with a speeding trigger, as there was no precipitating event. No reliability checks were performed on this variable; the average value of the two data analysts' results was used as the final value.

3.7.1.5 Data Transmission

Once data reduction and reliability checks were completed, the reduced data set was sent to the study team for analysis. The data set was stored on a secure, password-protected server. Contained in the data set was the categorical reduction for each false safety trigger and SCE, including:

- A unique time/date.
- GPS location of the event.
- Carrier ID number.
- Unique driver ID number.
- Unique event ID number.
- Trigger type.
- Severity of SCE (including a crash, near-crash, or other event).
- The categorical reduction (including the standard Lytx protocol and the additional reduction variables).
- The maximum kinematic values.

3.7.2 Smartphone App Data

Participants used the custom smartphone data collection app every day throughout the 5 months of data collection at the following points in time:

- At the beginning of a duty period before driving, on a smartphone (approximately 10 minutes):
  - Driver completed sleep/wake/duty diary.
  - Driver performed a 3-minute behavioral alertness test (PVT-B).
  - Driver rated fatigue on a fatigue scale (FS).
  - Driver rated sleepiness on the Karolinska Sleepiness Scale (KSS).
- During a break from driving, about halfway through a duty period, on a smartphone (approximately 5 minutes):
  - Driver performed a PVT-B.
  - Driver rated stress (SS).
  - Driver rated fatigue (FS).
  - Driver rated difficulty of drive.
  - Driver rated degree of drive hazards.
  - Driver rated sleepiness (KSS).
- At end of a duty period after driving, on a smartphone (approximately 10 minutes):
  - Driver performed a PVT-B.
  - Driver rated fatigue (FS).
  - Driver rated sleepiness (KSS).
  - Driver completed sleep/wake/duty diary.

Participants also used the app during restart days to provide the same measures at a time within 2 hours of waking, about midway through the waking period, and within 2 hours of sleeping. The app detected motion and did not allow participants to complete the smartphone-based PVT-B while the vehicle was in motion. For team drivers, the study team provided instructions to the off-duty driver in the sleeper berth to complete assessments at the same time as his or her driving partner before the drive, after the drive, and when taking a break.

3.7.2.1 Data Transmission and Reduction

Smartphone app data (PVT-B, sleep diary, caffeine log, etc.) were collected and transmitted in real-time via secure mobile data link to a server. Raw PVT-B data, sleep diary and caffeine log entries, and other questionnaire data were parsed and secondary metrics calculated. Data quality control analyses included programmatic scripts and manual review to detect missing, spurious, or corrupt data, and device hardware or software failures. Weekly data quality reports were generated to support weekly participant telephone debriefings.

After the data quality control process was completed, de-identified data were formatted and transmitted for statistical analysis. Data were automatically uploaded and securely transferred to the research team to support near-real-time data collection, quality control, and variables extraction.

3.7.3 Electronic Logging Device Data

ELD data were collected using a variety of approaches based on the carrier's deployed ELD solution. In cases where a carrier did not have an ELD solution, one was provided during the study (the BigRoad app with DashLink was delivered on the study-issued smartphone).

3.7.3.1 Data Transmission and Reduction

The study team developed an ELD data flow plan for each carrier based on the technology used and a carrier-specific work flow. The goal was to collect ELD data as frequently as possible in a manner that had the smallest impact on carriers. ELD data were collected and variables related to driver status were extracted (i.e., timing and duration of driving, working, sleeper berth, and off-duty) to provide the primary independent study measure in the aggregate analysis.

3.7.4 Actigraph Data

Participants wore ActiGraph's wGT3X-BT actigraph devices on their wrists during the study to measure sleep timing and quantity. The rechargeable battery lasted 7–14 days with wireless transmit mode enabled. Each participant received a universal serial bus charger with an alternating current wall adapter and 12-volt cigarette lighter adapter to enable charging in the vehicle. Devices took approximately 2 hours to charge. Participants were instructed to remove and charge the actigraph device once per week (e.g., every Wednesday). As the data were uplinked in near-real-time (i.e., daily), the study team was aware of any problems with the device, such as a dead battery, and contacted the participant promptly to troubleshoot the problem.

3.7.4.1 Data Transmission and Reduction

Actigraph data were transmitted in real-time via secure mobile data link to the study team's server. Raw actigraph data were parsed and secondary metrics calculated. Data quality control analyses included programmatic scripts and manual review to detect missing, spurious, or corrupt data, and device hardware or software failures. Weekly data quality reports were generated to support weekly participant telephone debriefings. Data were automatically uploaded and securely transferred to the study team to support real-time data collection, quality control, and variable extraction.

Sleep was manually scored by a research assistant who received training in scoring actigraph-based sleep records. Sleep was scored in 1-minute epochs for every minute during participants' data collection period. Sleep was scored as either "awake," "asleep," or "unknown" based on data from the actigraph device and the sleep diary. These data were cross-referenced with ELD data to ensure data consistency. Each epoch was additionally assigned a code indicating which data sources contributed to the determination for that epoch according to the rules in Figure 8. For example, if a driver recorded a sleep period in the smartphone-based sleep log and the data from that driver's actigraph device also indicated sleep, then all of those 1-minute epochs would be scored as sleep. If a driver did not provide a sleep entry in the smartphone-based sleep log for a given 24-hour period, but the data from that driver's actigraph device indicated sleep, then the period of time would be scored as sleep. If the actigraph indicated continuous movement it would be scored as wakefulness. If a driver did not provide a sleep entry in the smartphone-based sleep log for a given 24-hour period, and the actigraph record for the same 24-hour period was missing data (e.g., due to battery failure), the adjudicated scoring would indicate missing data.

ACTIGRAPHY and SLEEP DIARY were jointly used to adjudicate sleep-wake times	Driver SLEEP DIARY had sleep time entered	Driver SLEEP DIARY did not have sleep time entered
Driver ACTIGRAPHY data indicated sleep	Scored as **SLEEP TIME** based on agreement of actigraphy and diary	Scored as **SLEEP TIME** based on actigraphy
Driver ACTIGRAPHY data indicated wakefulness	Scored as **WAKE TIME** based on actigraphy	Scored as **WAKE TIME** based on actigraphy
Driver ACTIGRAPHY data was missing or off-wrist	Scored as **SLEEP TIME** based on diary	Scored as **MISSING DATA**

Figure 8. Chart. Rules for adjudicated sleep scoring using participants' actigraph records and sleep diary logs.

3.8 METHODOLOGY LIMITATIONS

The smartphone required daily battery recharging, and a driver could also use it for data input and submission by plugging it into a charger. The actigraph device required a battery recharge every 7–14 days. When the battery failed to be recharged, data were not received and the driver was sent a replacement actigraph device with a new battery. Study staff contacted drivers weekly regarding the charging status of the devices and any replacement equipment being sent to them. Sections 2.4.2 and 2.3.1 detail the data acquired with the devices and the extent to which data were lost due to battery discharge or damage to the devices.

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4. ANALYSIS PLAN AND DATA PROCESSING

The study used a naturalistic approach defined as an "unobtrusive observation or observation taking place in a natural setting"[46] to evaluate the impacts of Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations. Specifically, the study addressed two HOS provisions:

- First, potential effects of a 1-night restart duty cycle, relative to a 2-night or more-than-2-night restart duty cycle.
- Second, the potential effects of taking a restart in 168 hours or more following the beginning of the prior restart compared to taking a restart in less than 168 hours. These were evaluated relative to selected operational, safety, health, and fatigue outcomes.

The ELD data generated from each driver were partitioned into sampling units (SUs). SU partitioning, as executed, was required to meet the study objectives, and is consistent with the study work plan.[47] This section describes the conceptual model used and defines the primary concepts implemented using a computer-based algorithm.

4.1 CONCEPTUAL MODEL USED TO PARTITION ELECTRONIC LOGGING DEVICE RECORDS INTO SAMPLING UNITS

Figure 9 summarizes the conceptual model that guided the data reduction procedures used to partition each driver's ELD data into discrete SUs. By definition, each SU was comprised of a restart period (***R***), followed by a duty or non-restart period (***NR***). The letter '***t***' signifies a specific sampling unit [***SU(t)***], and by extension, its corresponding ***R(t)*** and ***NR(t)***. A central component to this model was that every ***R(t)*** was classified according to the restart provisions described above.

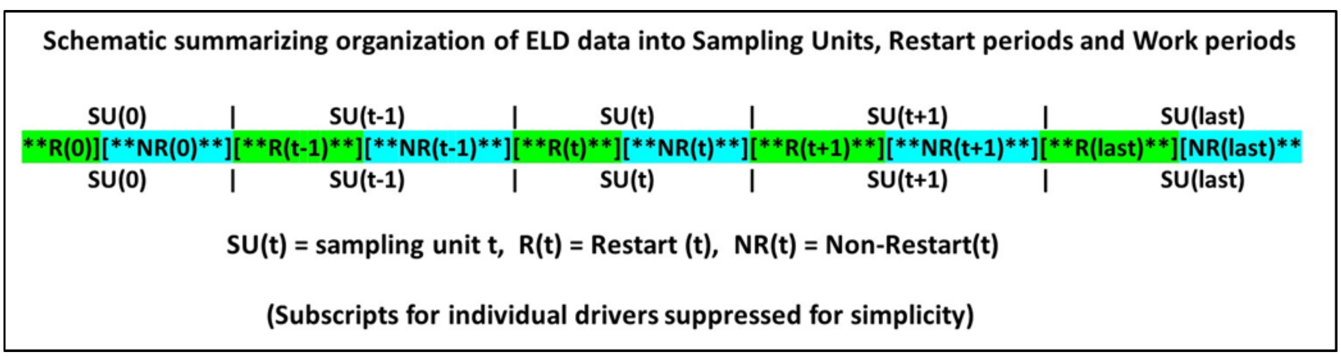

Figure 9. Schematic. Organization of ELD data into SUs, restart periods, and work periods.

The distributions of the operational, safety, health, and fatigue outcomes determined during ***NR(t)*** were compared among ***SU(t)***s that had been categorized according to provision use associated with the corresponding ***R(t)***. In some cases, outcomes defined within ***R(t)*** itself were relevant (e.g., mean daily sleep during ***R(t)***).

The notation defined above was formally extended to identify specific drivers, i = 1 to N_D, as in ***SU(i,t)***, where N_D was the number of enrolled drivers contributing at least one valid ***SU(t)***.

Among the 242 enrolled drivers, N_D = 235 contributed at least one ***SU(t)***. The reasons for lack of contributing at least one sampling unit are summarized below.

In this way, the follow-up periods as reflected in the ELD data for each driver were partitioned into sampling units ***SU(i,t)*** (***i***=1 to ND, ***t***=1 to T) and each ***SU(i,t)*** was constructed to include exactly one ***R(i,t)*** period followed by exactly one ***NR(i,t)*** period. For example, ***R(3,5)*** denotes the 5th restart period for driver 3 and ***NR(100, 10)*** is the 10th non-restart period, that is, the 10th work duty cycle for driver 100.

4.1.1 Electronic Logging Device Data Handling

The ELD data were collected from participating carriers and independent drivers as necessary. The ELD records were delivered in varying formats, which were converted into a standardized format. Consistency checks and other methods of validation (described above) were conducted. Each file contained date-times of ELD status changes recorded by the driver in UTC and home terminal time, as well as a truck ID number necessary for cross-linking with a specific OBMS installed in an instrumented truck. This cross-linking was necessary for defining “instrumented hours driving” for each ***SU(t)*** included in the data analysis to obtain more accurate measures of “exposure” for the SCEs.

4.1.2 Electronic Logging Device Sampling Unit Identification Algorithm

The driver-specific ELD history files served as the input for the ELD SU identification algorithm. This algorithm was based on the use of Statistical Analysis Software (SAS) Proc Expand. It begins by expanding the set of status change onsets into a minute-by-minute chronology in which each minute is classified according to the ELD status types of:

1. Driving.
2. On-duty.
3. Off-duty.
4. Sleeper Berth.

These ELD status types were further simplified to “working” (driving or on-duty) and “not working” (off-duty or sleeper) for the purpose of implementing the algorithm. It is important to highlight the definition of the ELD status “sleeper.” This was time spent in the truck’s sleeper berth, but does not necessarily imply the driver was actually sleeping. It only indicates the driver reported he or she was in the truck’s sleeper berth, which was classified—along with “off-duty”—as “not working” time.

The ELD data that serves as input in the algorithm includes confidential information protected by the VTTI IRB. These data are analogous to video files that contain personally identifying information. Thus, the protected components of the ELD data are not included in the public data set.

To summarize, the ELD SU identification algorithm was used to determine the onset and completion of each ***R(i,t)*** and ***NR(i,t)*** for each driver. The ***R(i,t)***s were identified sequentially as any period in which there were at least 34 consecutive hours in which the ELD status indicated "not working." The interval of time until the onset of the next 34 consecutive hours (minimum) of "not working" was then defined as ***NR(i,t)***. By construction and consistent with regulations, the ***R(i,t)***s could include only "off-duty" or in "sleeper." An ELD status of "on-duty" or "driving" would necessarily end ***R(i,t)***. ***NR(i,t)***s could consist of all four possible ELD status types (i.e., on-duty, driving, off-duty, and sleeper).

4.1.3 Quality Assurance Procedures

The raw ELD data files contained information reflecting driver behavior that could be used to identify specific drivers. Therefore, the raw ELD records collected during this study are protected and cannot be made available to the general public. Consequently, the study team determined it was essential to validate the output of the ELD sampling unit identification algorithm. In general, there are two key methods to validate such programming: "double programming" and "code review." Both methods were used to ensure the outputs from the algorithm were valid, including the partitioning of the ELD records into sampling units and determining the beginning and end of every restart period and duty period. Double programming was accomplished by having the algorithm independently programmed by two different organizations within the research team using different programming platforms. Initially, one member of the research team programmed the algorithm using MATLAB (a proprietary programming language). Results from these preliminary findings were provided to the study team in an ongoing fashion. Simultaneously, another member of the research team programmed the algorithm in SAS with special attention as to how outcome variables could be assigned to each restart and duty period as appropriate. As the SAS algorithm matured, results were compared to those produced by the MATLAB algorithm. Differences in results between the algorithms were investigated and resolved in an ongoing fashion, including substantial discussion between responsible parties. The same process was used for counting the SCEs. At the end of this process, quality metrics revealed greater than 99 percent agreement on all relevant variables.

In addition to double programming, code review was performed on multiple occasions. Code review involved the primary programmer explaining to another programmer the logic of key program elements. This method is effective in identifying code segments with potential logical problems and included line by line inspection of key elements in the algorithm. Similar quality assurance checks were performed on the other outcome variables (e.g., actigraphy, sleep diary, KSS, etc.). This included comparing counts of testing bouts (e.g., PVT-B and driver-reported outcomes) from the source data to the numbers of testing bouts included in the final analysis data sets produced by the analysis team. Finally, in addition to the above, the study team reviewed marginal distributions of outcomes prior to unblinding (see Section 4.2) to assess scientific and logical plausibility. This process was repeated after unblinding. In total, these quality assurance procedures ensured the analyses were performed on the highest quality data possible.

4.2 BLINDING OF OUTCOME VARIABLES TO AVOID ANALYSIS BIAS

A number of decisions and assumptions were made to implement the data reduction plan and the analysis plan. To avoid conscious (or subconscious) bias, the study team decided to keep the outcome data, including PVT-B outcomes; driver-reported responses pertaining to sleepiness, fatigue, stress, hazards and difficulty of drive; adjudicated estimates of sleep duration; and

OBMS event data blinded from the primary study statistician, the project technical lead, and other members of the study team, and from FMCSA. This was implemented by having the primary study analyst randomly sort outcome data before attaching outcomes to the ***SU(t)***s when constructing the preliminary analysis datasets. In this way, the distributions of outcome variables could be reviewed and beta testing of descriptive and statistical analyses was performed without concern that decisions would bias the results in one direction or another. Only when all quality-related data decisions, such as exclusions of SUs from the analysis set and statistical models for testing primary hypotheses were specified, were the outcome variables unblinded with regard to the real ***SU(t)*** and associated provisions to which they belonged.

4.3 TRUNCATION AND EXCLUSION OF SU(T)S

In preliminary analyses, it was observed that some lengths of ***SU(t)***s were several months long. There were several reasons for this. In some cases, this reflected the driver's behavior (e.g., the driver simply did not have periods of at least 34 consecutive hours "not working," preventing the algorithm from terminating the ***NR(t)*** period). In other cases, it was determined the driver did not log off his or her ELD prior to leaving work for an extended period, such as a vacation. Finally, regardless of the particular reason, the study team decided the maximum length of ***NR(t)*** should be 14 days. This length of time was long enough to capture outcomes during periods of time in which it was reasonably expected the provisions may have impacted the driver's safety, fatigue, operations, and health. Moreover, there was little or no evidence that changes in behavior implied by provision use extend beyond 14 days for the outcomes of interest in this study. The 14-day truncation rule was observed to produce distributions that contained fewer outliers, likely due to artifacts in the ELD records.

4.3.1 Exclusions

As described below, the ELD SU identification algorithm generally produced partitions of the ELD follow-up into ***SU(t)***s with mean driving time and on-and off-duty times per day that had substantial face validity during ***R(t)*** and ***NR(t)***. However, in some cases, the ***NR(t)***s appeared too short to provide a meaningful assessment of outcomes in general. Furthermore, when evaluating SCE rates, there was a further reduction in the estimated hours driving since only hours driving in an OBMS-instrumented truck provided "exposure time" for SCEs. Therefore, the following exclusion criteria were employed. All data from ***SU(t)***s meeting any of the following criteria were excluded from the analysis to test the effects of the provisions on the outcome variables. Appendix I and Appendix J provide listings of excluded ***SU(t)***s. In total, 315 of 3,602 ***SU(t)***s were excluded (resulting in 3,287 sampling units) based on the following criteria (note that a driver could have had more than one of these exclusion criteria):

1. Exclude ***SU(t)***s with total driving time less than 4 hours (154 exclusions).
2. Exclude ***SU(t)***s with ***NR(t)***s that were less than 1 day (270 exclusions).
3. Exclude ***SU(t)***s with mean driving time per day more than 20 hours and total driving time more than 300 hours (2 exclusions).
4. Exclude ***SU(t)***s with ***NR(t)***s that were more than 87 days (2 exclusions).

4.4 PROVISION USE

The HOS data in the ELD files were similarly processed to determine the primary independent variables related to Section 395.3(c). To this end, each ***R(t)*** was classified according to whether the consecutive period of at least 34 hours included one period of 1–5 a.m. versus two or more such periods. To add clarity to the interpretations, the study team decided to also evaluate comparisons among SUs with one period of 1–5 a.m. versus those with exactly two such periods, versus those with three or more such periods. Similarly, to evaluate the impact of Section 395.3(d), each ***R(t)*** was classified according to whether the elapsed time from the initiation of the prior restart to the initiation of next restart was at least 168 hours or less than 168 hours.

4.4.1 Numbers of Nights Per Restart

The number of nights in ***R(i,t)*** was determined by counting the number of 1–5 a.m. pairs that occurred during this time period. This allowed each ***SU(i,t)*** to be categorized as 1 night, 2 nights, or more than 2 nights. The impacts of Section 395.3(c) on selected operational, safety, health, and fatigue outcomes were assessed by comparing SUs with 1 night versus 2 or more nights, and by comparing SUs with 1 night to those with 2 nights (versus more than 2 nights).

4.4.2 Restart in at Least 168 Hours Versus Less Than 168 Hours

For Section 395.3(d), provision use was determined according to the number of hours from the beginning of the prior restart, ***R(i,t-1)***, to the initiation of ***R(i,t)***. This time period was exactly equal to the length of ***SU(i,t-1)***, implying the first SU could not be categorized according to this provision. Therefore, the ***SU(i,t=1)***s could not be used for the comparisons of SUs with less than 168 hours versus at least 168 hours, and when both provisions were evaluated simultaneously, such as in multivariable statistical models.

4.4.3 Determining Time of Day

Time of day in the study was set to the driver's home terminal time zone. If a driver changed jobs and home terminal time zones, then time of day was set to new home terminal time zone.

4.5 ONBOARD MONITORING SYSTEM EVENT LINKING AND "INSTRUMENTED HOURS DRIVEN"

Linking the thousands of captured SCEs and false safety triggers to participating drivers presented special challenges. The first challenge was dealing with SCEs and false safety triggers from drivers not participating in the study. If a SCE or false safety trigger occurred while a particular driver had an ELD status of anything but "driving," it was concluded the OBMS was not capturing the study driver. These instances could include various situations, such as a mechanic driving the truck, team drivers (where only one of the team drivers participated in the study), or slip-seat drivers (where several drivers were driving several trucks). These SCEs and false safety triggers were not matched and were excluded from all analyses.

The second challenge involved a study driver driving a truck other than the OBMS-instrumented truck. Here "instrumented" means the participating driver was driving in a truck with an operational OBMS that was associated with that driver (at least during this time interval).

“Operational” means the OBMS was working as intended, with no reported technical issues. Each driver’s ELD file included a specific truck ID. Each SCE and false safety trigger was checked against the driver’s ELD status and specific truck ID.

The third challenge involved non-operational OBMSs. If the OBMS experienced technical issues or there was abuse/obstruction of the OBMS (e.g., camera was obscured), this was indicated for the event. These types of OBMS issues could render the OBMS unreliable for accurately capturing SCEs and false safety triggers. Some of these SCEs and false safety triggers required troubleshooting with the driver prior to being deemed reliable. These times were defined as non-instrumented driving time and not included in the denominators when determining SCE and fatigue-related false safety trigger rates. A separate file containing the dates a specific OBMS was non-operational/operational was provided. Upon resolution of the OBMS issue, driving time may have been considered “instrumented.”

The following strategy was used to link SCEs and false safety triggers to specific drivers. A key concept was that these events were linked to a specific OBMS (which was also linked to a specific truck ID). An SCE or false safety trigger was considered correctly linked to a specific driver if the following three conditions were met:

- Complete driver accounting in the “linking” document.
- ELD data included truck ID for that time period.
- SCEs and false safety triggers included a date-time stamp that matched the date-time stamp to a time in which it was known the driver was driving a truck with an operational OBMS. Indication of a non-operational/unreliable OBMS was considered not-instrumented time. This not-instrumented time ends with successful troubleshooting.

The linking document recorded the date of installation (and subsequent installation, if necessary) with the OBMS ID (and secondary or tertiary OBMS ID, if applicable). The criteria above were necessary and sufficient for determining the driving times per SU (during periods when participants were driving in instrumented trucks with fully operational OBMSs that accurately captured SCEs and false safety triggers). During driving times classified as “not instrumented,” SCEs and false safety triggers were not matched, but were not given counts of 0 for this time. Rather, the hours of driving exposure were reduced to accurately reflect the true “driving-while-instrumented” time. Similarly, for each SU, hours in which the OBMS was “not operational” were subtracted from total hours driving and a new variable was constructed—“total instrumented driving time per sampling unit.” This approach was also applied to single-truck, multiple-driver situations (e.g., team drivers and slip-seat drivers).

4.5.1 Summary of Approach for Defining Exposure to SCEs

In summary, for each SU, the following numerators and denominators were determined. The numerator equals the number of “confirmed” SCEs or false safety triggers per SU. The denominator equals the number of “instrumented” hours driving per SU. “Confirmed” means it was known, based on the three criteria listed above, that the SCE or false safety trigger occurred while the specific driver was driving. “Instrumented” means the driver was driving in a truck with an operational OBMS that was associated with that driver (at least during this time interval).

4.6 MIXED-EFFECTS STATISTICAL MODELS

Formal statistical comparisons, including testing of the primary and secondary hypotheses concerning differences in expected outcome on the basis of provision use, were performed using linear[48,49] and non-linear[50] mixed-effects modeling. These analyses were performed using the SAS/STAT® procedures MIXED and GLIMMIX (version 9.4), respectively. The objectives of using the mixed modeling approach were to reduce potential bias and confounding arising from the observational naturalistic study design and to account for correlations among multiple outcomes from the same driver and among multiple outcomes observed within the same sampling unit.

Every model included a factor for the number of nights included in the restart period (1 night versus 2 nights versus 2 or more nights), use of the 168-hour provision, and a factor for restart nights by 168-hour provision interaction. Models also included a set of a priori selected covariates specified in the work plan. These covariates included age and body mass index (BMI) as continuous variables, and the following baseline categorical variables: prior participation in a fatigue management program, gender, marital status, diabetes, high blood pressure, insomnia, sleep apnea, pain experience, use of caffeine, and use of tobacco. Models also included two factors obtained prior to each restart period. These factors related to drivers' planned number of restart nights on their next restart and the reason for this decision. Finally, models for outcomes collected multiple times per day included a time-of-day factor defined according to home terminal time:

- 12 a.m. (midnight) to 3:59 a.m.
- 4 a.m. to 7:59 a.m.
- 8 a.m. to 11:59 a.m.
- 12 p.m. (noon) to 3:59 p.m.
- 4 p.m. to 7:59 p.m.
- 8 p.m. to 11:59 p.m.

Using these covariates, estimated predicted mean values for type of provision use were weighted to reflect the characteristics in the obtained sample. Random effects were included in the mixed linear models to account for correlations among outcomes from the same driver and to account for any "extra" correlation among multiple observations within the same sampling unit for outcomes assessed multiple times. Linear mixed models were used for all continuous and ordinal outcomes. Generalized mixed-effects models were used for outcomes expressed as counts or rates. Details regarding the construction of the mixed-effects models are provided in Appendix K.

4.7 ADDRESSING SELECTION BIAS

As a consequence of being a naturalistic study, drivers self-selected the restart conditions which are the subject of this study. Therefore, adequate handling of selection bias was essential in order to provide for valid inference. Selection bias in this study was addressed in three ways: design-related, conduct-related, and analysis-related.

4.7.1 Design-related Selection Bias

It was recognized at the design stage that having drivers serve as their own control would be an effective way to minimize selection bias. Specifically, the design specified that in order to maximize statistical power for testing key hypotheses, participants would be prescreened according to whether or not it was expected that the participant's schedule was, or was not, likely to include at least one restart duty cycle of both types (1 night and 2 or more nights).

Within-driver comparisons derive their enhanced statistical power by filtering out between-driver "nuisance" variance (e.g., age, medical conditions, personality, etc.). This was an observational study in which participants self-selected their experimental condition. However, the study was designed to focus on within-driver comparisons in order to strengthen causal inferences to be derived on the basis of study data. Nonetheless, even participants with only one type of duty cycle (and who completed at least one duty cycle) contributed to the analyses using the mixed-effects statistical models employed. The mixed model analytic plan handled inequality in the cell frequencies, and drivers with less than all four types of restarts were included in and contributed to the analyses.

The efforts to observe drivers under multiple conditions was successful, with 132 (56.2 percent) of the 235 drivers contributing at least one 1-night restart and at least one restart with 2 or more nights. Moreover, 201 (87.4 percent) of the 235 contributing drivers had at least one restart within 168 hours of initiating their prior restart and at least one restart that was 168 hours or more since the start of their last restart. These relatively large percentages of participating drivers observed under multiple conditions mitigated the potential for selection bias. Non-parametric within-driver statistical comparisons based only on drivers contributing sampling units under multiple conditions were performed in parallel to parametric mixed-effects statistical modeling. The general similarity of results under the two analysis approaches provided evidence supporting the notion that the primary mixed-effect modeling results (with covariate adjustment as discussed below) were not subject to enough selection bias to invalidate statistical estimates of mean differences.

4.7.2 Conduct-related and Analysis-related Selection Bias

Notwithstanding the within-driver design features discussed above, some drivers were, in fact, not observed under both provision conditions for particular comparisons. Therefore, a statistical modeling approach was employed to address residual selection bias.

Ideally, any non-randomized group comparison should be "designed" prior to analysis, just as randomized group comparisons should be. Here "design" may be interpreted as the "contemplating, collecting, organizing, and analyzing of data that takes place prior to seeing any outcome data."(51) Useful design efforts are a hallmark of good randomized clinical trial practice. It is widely accepted that these design efforts minimize bias and produce efficient treatment group comparisons. A principled approach in performing treatment group comparisons in observational studies includes a priori specification of the details regarding the treatment group comparison without access to outcome data. This approach was used to compare between outcomes assessed under varying provision use, thereby reproducing the desirable features of randomized designs to the extent possible.

Consistent with the above, the following occurred: a set of baseline covariates was specified in the work plan prior to driver enrollment. Baseline covariates were selected on the basis of their potential association with outcomes as determined through the expert literature review. At the recommendation of the Peer Review Committee, weekly calls were made to drivers to determine their intended provision use and reasons for selection. Outcome data were blinded to the study statistician and to most of the study team throughout the data collection phase and the preliminary analysis phase. This was accomplished by randomly sorting outcome data in a fashion depending upon the data collection timing before attaching outcome data to sampling units. The analysis data set allowed for visualization of marginal outcome distributions, but only 'pseudo' comparisons among provision conditions were possible. This blinding of all outcomes variables was maintained until after all sampling unit exclusion and related decisions were made.

One potential limitation to covariate adjustment as implemented in this study was that, unlike comparisons based on randomized groups, bias reduction could only be based on observed variables that were included in the model. Nonetheless, "bias from unobserved covariates can be removed to the extent that they are correlated with the observed x after adjustment."[(52)] The covariate set was defined to include information from multiple demographic and health domains; thus, the set of variables was likely to have at least some association with important variables that were not included in the covariate model.

An alternative to a covariate adjustment model for control of selection bias was to use the propensity score approach. "The propensity score is the observational study analogue of complete randomization in randomized experiments in the sense that its use is not intended to increase precision but only to eliminate systematic biases in treatment-control comparisons."[(53)] Moreover, the "propensity score technique allows the straightforward assessment [of] whether the treatment groups overlap enough regarding baseline covariates to allow for a sensible treatment comparison."[(54)]

Although covariate adjustment, rather than propensity scores, was used to account for residual selection bias, propensity score analysis was used to assess the validity and potential effectiveness of the covariate adjustment model. To this end, three logistic regression models were estimated. Predictor variables included all baseline and sampling unit specific covariates. The outcome variables were 1-night restart versus 2-or-more-night restart; 1-night restart versus 2-night restart; and <168 hours versus ≥168 hours since start of prior restart. Model-based predicted probabilities for one condition versus the other were evaluated graphically and using summary statistics. The overall association between the covariates and the provision condition was assessed using a concordance or 'c-statistic.'[(55)] The value of the c-statistic can be interpreted as the probability that a randomly selected sampling unit observed under, as an example, a 1-night restart has a higher predicted probability of being a 1-night restart than a randomly selected sampling unit with a 2-night restart. The predicted probabilities (PP) are first-order approximations to the propensity scores.

For the comparison between 1-night restart and 2-or-more-night restart, the median (number; range) PP values were 0.14 (426; 0.01–0.55) and 0.10 (2,861; 0.01–0.55), respectively, with c-statistic = 0.68. This value indicates that about two-thirds of the time, the model correctly orders pairs of sampling units. This is a reasonable amount of predictive power for use in covariate adjustment. Graphical displays confirmed reasonable overlap throughout the range of PP scores. These results provide evidence supporting the validity of the covariate adjustment model for accounting for residual selection bias. The PP scores significantly discriminate between conditions, yet high and low values were observed in both conditions. This is the situation in which covariate adjustment may be expected to be effective in controlling for selection bias. Similar findings were observed in the comparison between 1-night restarts and 2-night restarts. The median (number; range) PP values were 0.24 (426; 0.02–0.64) and 0.17 (1,577; 0.02–0.64), respectively, with c-statistic = 0.67. Graphical displays also confirmed reasonable overlap throughout the range of PP scores.

In contrast, the covariate model for the 168-hour provision was not predictive. Median (number; range) values were 0.49 (1,482; 0.38–0.63) and 0.47 (1,592; 0.34–0.63) with c-statistic = 0.56. This finding was not unexpected since the sampling unit specific covariates focused on the number-of-nights provision. Fortunately, most drivers were observed under both 168-hour conditions, which provides substantial control of selection bias for comparisons involving this provision. Regarding the weekly predictions, among the 625 sampling units in which drivers predicted they would take a 1-night restart, 25 percent (or 156 sampling units) were actually 1-night restarts and 75 percent (307 of the sampling units) were 2-or-more-night restarts. In contrast, among the 2,313 restarts in which drivers predicted they would take a 2-or-more-night restart, 90 percent (2,085 of the sampling units) were 2-or-more-night restarts, and only 10 percent (228 sampling units) were 1-night restarts. There were 349 sampling units missing their weekly prediction. Among these, 12 percent (42 sampling units) were 1-night restarts and 88 percent (307 sampling units) were 2-or-more-night restarts. The reason for choice also provided discrimination. When the decision was the company's decision, 18 percent (98 of the 538 sampling units) of the sampling units turned out to be 1-night restarts. A similar finding was observed when the decision was "largely due to Federal regulations" (17 percent, or 59 of the 352 sampling units). However, when the locus of control was perceived to be "largely my decision, but based on personal preference," only 9 percent (104 of the 1,104 sampling units) of subsequent sampling units turned out to be a 1-night restart.

In summary, the above analyses of predicted probabilities in conjunction with the relatively large numbers of drivers with sampling units observed under both conditions being compared provides substantial confidence that selection bias does not invalidate the findings from this study.

5. ANALYSES AND FINDINGS

The 235 participating drivers who contributed data for analysis provided a total of:

- 140,671 hours of driving time.
- 26,964 days of data:
  - 17,628 duty days.
  - 9,336 restart days.
- 3,287 restarts for data analyses:
  - 1-night restarts observed = 426.
  - 2-night restarts observed = 1,577.
  - More-than-2-night restarts observed = 1,284.
  - Restarts taken in less than 168 hours = 1,482.
  - Restarts taken in at least 168 hours = 1,592.

As indicated in the previous section, four sets of analyses were conducted. This chapter presents the results of those analyses. First, the results of descriptive analyses, which characterize the general makeup of the drivers that participated in the study, are presented. Second, the results of the analyses that focused on the impact of the provisions are presented. These analyses are directed at understanding if there were differences in the four outcome domains for either of the two provisions. Third, the within-subjects analyses results are presented. The within-subjects analyses increased statistical power beyond between-subjects analyses in that the former were constrained to drivers who experienced both provision options for Section 395.3(c) (i.e., restart in either 1 night, 2 nights, or more than 2 nights), or Section 395.3(d) (i.e., in less than 168 hours and at least 168 hours). Fourth, poolability analyses were conducted to break out the different industry segments for the drivers who participated in the study. The purpose of the poolability analyses was to determine if either provision impacted one segment of the participant groups (e.g., small carriers) differently than the other groups (e.g., medium or large carriers). Each of the four analyses is presented in turn.

5.1 DESCRIPTIVE ANALYSES

5.1.1 Distributions of Baseline Characteristics of Drivers

For the descriptive analyses, there were three areas of focus: demographics, medical history, and experience of pain.

5.1.1.1 Driver Demographic Characteristics

Table 9 highlights the demographic makeup of the 235 drivers who participated in the study. The participating drivers were generally similar demographically to the overall population of truck drivers in the United States. For example, 95 percent of the study drivers were male, and most drivers were between 40 and 60 years of age. This gender and age distribution was similar to what the American Trucking Associations has reported.[56] As shown in

Table 9, 12 percent of drivers had a normal BMI of less than 25, and 57 percent of drivers were either obese or morbidly obese. This is similar to the prevalence of obesity found in a survey of long-haul truck drivers completed by the National Institute of Occupational Safety and Health.[57]

Table 9 also highlights that the research team attempted to include a diverse group of drivers relative to provision use in terms of driving times (day, night, and mixed). There was geographical representation across the participants, though most were from the east and central regions of the continental United States, consistent with many of the carrier locations in the United States.

Table 9. Drivers' self-reported demographic characteristics.

Demographic Characteristic	N	Percent
Driver Sex: Male	224	95.3
Driver Sex: Female	11	4.7
Driver Age: 20–29	24	10.2
Driver Age: 30–39	44	18.7
Driver Age: 40–49	72	30.6
Driver Age: 50–59	77	32.8
Driver Age: 60–69	18	7.7
BMI > 40 (Morbid Obesity)	31	13.2
30 ≤ BMI < 40 (Obese)	103	43.8
25 ≤ BMI < 30 (Overweight)	74	31.5
BMI < 25 (Normal)	27	11.5
Marital Status: No	96	40.9
Marital Status: Yes	139	59.2
Driver Type: Drove Mostly During Day	24	10.2
Driver Type: Drove During Day & Night Mixed	176	74.9
Driver Type: Drove Mostly During Night	35	14.9
Home Terminal Time Zone: Eastern	130	55.3
Home Terminal Time Zone: Central	83	35.3
Home Terminal Time Zone: Mountain	5	2.1
Home Terminal Time Zone: Pacific	17	7.2

5.1.1.2 Driver Medical History

Table 10 highlights findings from self-reported medical history and use of caffeine and tobacco. Twenty percent of the participants reported having high blood pressure, and sleep apnea was reported by 10 percent. The high prevalence of the medical conditions noted in Table 10 is similar to findings in other studies.[58] Most of the drivers reported using caffeine, and approximately half indicated use of some type of tobacco.

Table 10. Drivers' self-reported medical history and caffeine and tobacco use.

Medical History, Caffeine, and Tobacco Use	N	Percent of Total
Diabetes	21	8.9
High Blood Pressure	47	20.0
Insomnia	2	0.9
Sleep Apnea	24	10.2
Consumes Caffeine	217	92.3
Uses Tobacco	113	48.1

5.1.1.3 Experience Pain

Table 11 shows the results of a self-report question that asked drivers about their experience of pain during their shifts. As the table indicates, this did not seem to be a significant issue for most study participants.

Table 11. Drivers' self-reports on how often they experience pain during a typical daily work shift.

Percent of Shift Experience Pain	N	Percent
0–5%	185	78.7
5–25%	28	11.9
25–50%	13	5.5
50–75%	6	2.6
≥75%	3	1.3

5.2 RESULTS OF MIXED-EFFECTS MODELS FOR THE EFFECTS OF PROVISIONS

The next set of results highlights the analyses that were conducted to assess the impacts of the provisions. The impacts of the two provisions were studied with respect to the operational, safety, fatigue, and health outcomes. Each of these four outcome domains is presented in turn.

5.2.1 Operational Outcomes: Linear Mixed-effect Model

Operational outcomes included the following variables for duty periods: driving hours, working hours, perceived difficulty of drive, and perceived safety hazards. A total of 3,287 sampling units among 235 drivers were available for evaluation of the operational outcomes.

5.2.1.1 Driving Hours in Duty Periods

As shown in Table 12, statistically-predicted mean driving hours per day ranged between 8.00 hours and 8.22 hours for all uses of the provisions (rows 1, 2, 3, 8, and 9). Relative to Section 395.3(c), drivers spent more time driving in the duty period following a 1-night restart than they did following a more-than-2-night restart ($p = 0.0180$, row 5); the same was true for the average of a 2-night restart and a more-than-2-night restart ($p = 0.0337$, row 7). However, the driving increases were modest, ranging from 10–13 minutes. There was no effect on driving time relative to Section 395.3(d). DF, or degrees of freedom, is the number of values in the calculation of a statistic that are free to vary.

Table 12. Linear mixed-effect model: mean daily driving hours per 24 hours in duty periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	8.2166	0.1298	475	.	.
2	395.3(c)	2-night restart (R2)	8.0751	0.1102	255	.	.
3	395.3(c)	>2-night restart (>R2)	7.9982	0.1116	270	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.1415	0.0870	3123	1.63	0.1038
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.2184	0.0923	3141	2.37	0.0180*
6	395.3(c)	Difference between 2-night restart and>2-night restart (R2 minus >R2)	0.0769	0.0588	3122	1.31	0.1906
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.1800	0.0847	3134	2.12	0.0337*
8	395.3(d)	<168 hours between restarts	8.0557	0.1108	261	.	.
9	395.3(d)	≥168 hours between restarts	8.0576	0.1094	249	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0020	0.0542	3101	-0.04	0.9710

*Statistically significant difference at .05 level.

5.2.1.2 Working Hours in Duty Periods

Table 13 shows that similar to driving time and use of Section 395.3(c), drivers spent more time working in the duty period following a 1-night restart than they did in the duty period following a more-than-2-night restart (p = 0.0213; row 5), and more time working in a duty period following a 2-night restart than they did following a more-than-2-night restart (p = 0.0325; row 6). As with driving time, the work time increase between 1-night restarts and more-than-2-night restarts was only 6–13 minutes. There was no effect on work hours relative to the manner in which Section 395.3(d) was used.

Table 13. Linear mixed-effect model: mean daily working hours per 24 hours in duty periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	10.1978	0.1311	470	.	.
2	395.3(c)	2-night restart (R2)	10.1073	0.1100	241	.	.
3	395.3(c)	>2-night restart (>R2)	9.9765	0.1115	256	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.0905	0.0905	3121	1.00	0.3175
5	395.3(c)	Difference between 1-night and >2-night restart (R1 minus >R2)	0.2213	0.0960	3140	2.30	0.0213*
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.1308	0.0612	3118	2.14	0.0325*
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.1559	0.0882	3133	1.77	0.0771
8	395.3(d)	<168 hours between restarts	10.1132	0.1108	247	.	.
9	395.3(d)	≥168 hours between restarts	10.0339	0.1092	235	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0793	0.0564	3095	1.41	0.1599

*Statistically significant difference at .05 level.

5.2.1.3 Driver-rated Difficulty of Drive in Duty Periods

As shown in Table 14, use of the provisions in Sections 395.3(c) and 395.3(d) had no effect on drivers' ratings of the difficulty of the drive during the duty period. The statistically-predicted means for the subjective rating of difficulty of the drive were very similar across use of provisions, resulting in no significant differences.

Table 14. Linear mixed-effect model: mean driver-rated difficulty of drive in duty periods by provision condition (rated on a scale where 1 is "easy" and 5 is "difficult").

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	1.5454	0.0459	312	.	.
2	395.3(c)	2-night restart (R2)	1.5483	0.0423	228	.	.
3	395.3(c)	>2-night restart (>R2)	1.5450	0.0426	233	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0029	0.0223	2852	-0.13	0.8954
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0004	0.0236	2863	0.02	0.9857
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0033	0.0148	2734	0.23	0.8206
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0013	0.0217	2873	-0.06	0.9541
8	395.3(d)	<168 hours between restarts	1.5449	0.0424	231	.	.
9	395.3(d)	≥168 hours between restarts	1.5332	0.0423	227	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0117	0.0136	2736	0.87	0.3868

5.2.1.4 Driver-rated Safety Hazards in Duty Periods

In addition to rating the difficulty of the drive, drivers also rated the safety hazards experienced during the duty period. As shown in Table 15, there were no statistical differences between the two provisions with respect to drivers' perceived ratings of safety hazards during duty periods.

Table 15. Linear mixed-effect model: mean driver-rated safety hazards (1=few) in duty periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Differences	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	1.653	0.0509	311	.	.
2	395.3(c)	2-night restart (R2)	1.671	0.0469	226	.	.
3	395.3(c)	>2-night restart (>R2)	1.658	0.0472	231	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0188	0.0250	2856	-0.75	0.4522
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0058	0.0265	2868	-0.22	0.8281
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0130	0.0166	2738	0.79	0.4322
7	395.3(c)	Difference between 1-night restart and the average of a 2-night restart and >2-night restart	-0.0123	0.0244	2877	-0.50	0.6151
8	395.3(d)	<168 hours between restarts	1.665	0.0471	228	.	.
9	395.3(d)	≥168 hours between restarts	1.652	0.0468	224	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0133	0.0152	2740	0.87	0.3822

5.2.2 Safety Outcomes: Mixed-effect Model

Safety outcomes included the following variables for duty periods: SCEs and fatigue-related SCEs. A total of 2,988 sampling units among 226 drivers were available for evaluation of the safety outcomes (fewer drivers and sampling units were included in these analyses, which rely on OBMS data, due to some non-instrumented driving [see Section 4.5 for details]).

5.2.2.1 Safety-critical Events in Duty Periods

Non-linear mixed-effects modeling was used to evaluate whether the options afforded by either provision affected SCEs per 100 hours instrumented driving time in duty periods (Table 16). It is important to highlight that exposure was accounted for in this analyses by calculating a ratio of SCEs per 100 instrumented driving hours. As shown in Table 16, the means for each provisional condition were very similar. Table 17 highlights the results of statistical analysis conducted on these SCE data. As displayed in Table 17, there was no evidence that Sections 395.3(c) or 395.3(d) had an effect on SCEs.

Table 16. Non-linear (negative binomial) mixed-effect model: predicted means on the observed scale (inverse transformation) for SCEs per 100 hours instrumented driving time by provision condition.

Row	Section Relevance	Variable	Predicted Mean	Standard Error	DF
1	395.3(c)	1-night restart (R1)	0.3420	0.0476	213
2	395.3(c)	2-night restart (R2)	0.3688	0.0445	213
3	395.3(c)	>2-night restart (>R2)	0.3501	0.0427	213
4	395.3(d)	<168 hours between restarts	0.3589	0.0435	213
5	395.3(d)	≥168 hours between restarts	0.3680	0.0442	213

Table 17. Non-linear (negative binomial) mixed-effect model: predicted mean differences on the transformed (model) scale for SCEs per 100 hours instrumented driving by provision condition.

Row	Section Relevance	Variable	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0756	0.0857	131	-0.88	0.3792
2	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0236	0.0907	131	-0.26	0.7949
3	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0520	0.0547	131	0.95	0.3433
4	395.3(c)	Difference between 1-night restart and the average of a 2-night restart and >2-night restart	-0.0496	0.0839	131	-0.59	0.5552
5	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0251	0.0496	131	-0.51	0.6139

5.2.2.2 Fatigue-related SCEs in Duty Periods

The subset of OBMS event data categorized as fatigue-related SCEs resulted in a data set not substantial enough for statistical analyses. Therefore, fatigue-related SCE data were not analyzed to assess significant differences in rates for each provision condition.

5.2.3 Fatigue Outcomes: Mixed-effect Model

Four measures were used to assess fatigue during both duty periods and restart periods: PVT-B response speed (i.e., driver's mean 1/RT; also called reciprocal response time), PVT-B number of lapses (i.e., errors of omission), KSS sleepiness rating, and driver-rated fatigue on the FS. A total of 3,287 sampling units among 235 drivers were available for evaluation of each of these fatigue outcomes.

5.2.3.1 PVT-B Response Speed During Duty Periods

The PVT-B performance test provided objective information on drivers' psychomotor speed (i.e., mean reciprocal reaction times) and was the primary fatigue measure in the study. A higher number in the predicted mean column in Table 18 and Table 19 indicates better performance. There was limited evidence that PVT-B response speed was affected during duty periods relative to Section 395.3(c). As shown in Table 18 (row 6), there was an indication that PVT-B response speed was slightly slower following a more-than-2-night restart period compared to a 2-night restart period (p = 0.0103).

Table 18. Linear mixed-effect model: mean PVT-B response speed in duty periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.7905	0.0407	267	.	.
2	395.3(c)	2-night restart (R2)	3.7928	0.0389	223	.	.
3	395.3(c)	>2-night restart (>R2)	3.7667	0.0390	226	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0024	0.0153	2843	-0.15	0.8772
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0238	0.0162	2846	1.47	0.1425
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0262	0.0102	2756	2.57	0.0103*
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.0107	0.0149	2855	0.72	0.4722
8	395.3(d)	<168 hours between restarts	3.784	0.0389	224	.	.
9	395.3(d)	≥168 hours between restarts	3.766	0.0388	222	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0183	0.0094	2755	1.96	0.0503

*Statistically significant difference at .05 level.

5.2.3.2 PVT-B Response Speed in Restart Periods

Relevant to Section 395.3(c), PVT-B response speed was slightly slower during more-than-2-night restart periods compared to 1-night restart periods (p = 0.0067, Table 19, row 5), and slightly slower during more-than-2-night restart periods compared to 2-night restart periods (p = 0.0005), as shown in Table 19 (row 6). PVT-B response speed was somewhat slower relative to Section 395.3(d) when there were 168 hours or more between restarts, versus less than 168 hours between restarts (p = 0.0216, Table 19, row 10).

Table 19. Linear mixed-effect model: mean PVT-B response speed (mean 1/RT) in restart periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.7778	0.0395	293	.	.
2	395.3(c)	2-night restart (R2)	3.7673	0.0369	222	.	.
3	395.3(c)	>2-night restart (>R2)	3.7263	0.0369	224	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.0105	0.0181	3160	0.58	0.5611
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0515	0.0190	3027	2.71	0.0067*
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0411	0.0117	2666	3.51	0.0005*
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.0310	0.0176	3141	1.76	0.0779
8	395.3(d)	<168 hours between restarts	3.7580	0.0369	224	.	.
9	395.3(d)	≥168 hours between restarts	3.7331	0.0368	221	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0249	0.0108	2786	2.30	0.0216*

*Statistically significant difference at .05 level.

Table 18 and Table 19 suggest that PVT-B response speed may have been faster during duty periods than during restarts. Table 20 presents the result of this comparison. It shows a reliable, albeit modest, difference between PVT-B response speeds during restart periods versus during duty periods, with faster response times during duty periods ($p < 0.0001$).

Table 20. Linear mixed model for PVT-B response speed for duty period minus restart period.

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	0.0430	0.0026	69,000	16.40	<0.0001*

*Statistically significant difference at .05 level.

5.2.3.3 PVT-B Number of Lapses in Duty Periods

The second fatigue outcome measure was the number of lapses in PVT-B performance during the duty periods. A higher number in the predicted means column indicates worse performance. Table 21 shows the predicted means for PVT-B lapses were similar across the provisions and ranged from 2.90 (2-night restart) to 3.08 (more-than-2-night restart) for Section 395.3(c). For the 168-hour provision [Section 395.3(d)], the means ranged from 2.94 for restarts that occurred in less than 168 hours restarts to 3.09 for restarts that occurred in 168 hours or more.

Table 21. Non-linear (Poisson) mixed-effect model: predicted PVT-B lapse means during duty periods on the observed scale (inverse transformation).

Row	Section Relevance	Variable	Predicted Mean	Standard Error	DF
1	395.3(c)	1-night restart (R1)	2.9735	0.2413	275.1
2	395.3(c)	2-night restart (R2)	2.8969	0.2224	221.1
3	395.3(c)	>2-night restart (>R2)	3.0818	0.2375	224.4
4	395.3(d)	<168 hours between restarts	2.9410	0.2263	223
5	395.3(d)	≥168 hours between restarts	3.0860	0.2367	220.0

Statistical analysis using a non-linear (Poisson) mixed model was conducted on the frequency of PVT-B performance lapses. As shown in Table 22, the only statistically significant differences during duty periods were between restarts with 2 nights and those with more than 2 nights ($p = 0.0047$, row 3), and between the 168-hour provisions ($p = 0.0167$, row 5). PVT-B lapses were more frequent during duty periods after more-than-2-night restarts and more common when restarts occurred after 168 hours or more, compared to restarts that occurred in less than 168 hours. These statistically reliable differences were modest.

Table 22. Non-linear (Poisson) mixed-effect model: predicted mean differences on the model (transformed) scale for PVT-B total lapses by provision condition during duty period.

Row	Section Relevance	Variable	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.0261	0.0331	2595	0.79	0.4307
2	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0358	0.0351	2596	-1.02	0.3087
3	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.0619	0.0218	2481	-2.83	0.0047*
4	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0048	0.0323	2609	-0.15	0.8814
5	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0481	0.0201	2490	-2.40	0.0167*

*Statistically significant difference at .05 level.

5.2.3.4 PVT-B Number of Lapses in Restart Periods

Table 23 and Table 24 show the results for the number of PVT-B lapses during restarts. The mean values for the options of the two provisions are shown in Table 23. The ranges of mean values across each condition were more varied in the restart period as compared to the duty period.

Table 23. Non-linear (Poisson) mixed-effect model: predicted means on the observed (inverse transformation) scale during restart periods.

Row	Section Relevance	Variable	Predicted Mean	Standard Error	DF
1	395.3(c)	1-night restart (R1)	3.1623	0.2489	303.1
2	395.3(c)	2-night restart (R2)	3.1954	0.2310	217.3
3	395.3(c)	>2-night restart (>R2)	3.5943	0.2604	219.2
4	395.3(d)	<168 hours between restarts	3.2743	0.2372	219
5	395.3(d)	≥168 hours between restarts	3.4805	0.2509	215

A non-linear (Poisson) mixed-effect model analysis was conducted on the lapse data. The results are shown in Table 24. The relatively larger mean differences shown in Table 24 were significantly different across most comparisons (except 1-night versus 2-night restarts, row 1, and 1-night versus the average of 2-night and more-than-2-night restarts, row 4). As was found for the duty period (Table 22), there were more PVT-B lapses during restart periods when restarts involved more than 2 nights, and occurred in 168 hours or more.

Table 24. Non-linear (Poisson) mixed-effect model: predicted mean differences on the model (transformed) scale for PVT-B total lapses by provision condition during restart period.

Row	Section Relevance	Variable	Predicted Mean Differences	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0104	0.0391	2731	-0.27	0.7898
2	395.3(c)	Difference between 1-night restart and>2-night restart (R1 minus >R2)	-0.1281	0.0411	2656	-3.12	0.0019*
3	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.1176	0.0250	2339	-4.71	<.0001*
4	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0692	0.0381	2734	-1.82	0.0694
5	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0611	0.0233	2430	-2.63	0.0087*

*Statistically significant difference at .05 level.

Table 25 displays the results of comparing the PVT-B lapse rates between the duty periods and the restart periods. As can be seen in this table, there were more lapses during restart periods than during duty periods ($p < 0.0001$). This result is consistent with the finding for PVT response speed, which was slower in restarts than during duty periods (Table 20).

Table 25. Linear mixed model for PVT-B total lapses: mean difference of duty period minus restart period.

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	-0.0496	0.0036	65503	-13.61	<0.0001*

*Statistically significant difference at .05 level.

5.2.3.5 Karolinska Sleepiness Scale (KSS) in Duty Periods

The third fatigue outcome measure was subjective sleepiness as measured by the KSS. Values on the KSS range from 1 (“extremely alert”) to 9 (“extremely sleepy”). The mean values for duty periods relative to the provisions are shown in Table 26. They indicate drivers were rating themselves as generally “alert.” The table shows that their ratings of sleepiness on the KSS were not affected by the use of either restart provision [Section 395.3(c) and 395.3(d)].

Table 26. Linear mixed-effect model: mean driver KSS ratings in duty periods by provision condition (rated by driver on a scale of 1 “extremely alert” to 9 “extremely sleepy”).

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.4609	0.0775	266	.	.
2	395.3(c)	2-night restart (R2)	3.4720	0.0739	220	.	.
3	395.3(c)	>2-night restart (>R2)	3.4662	0.0741	223	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0111	0.0293	2937	-0.38	0.7045
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0053	0.0310	2892	-0.17	0.8638
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0058	0.0190	2589	0.30	0.7611
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0082	0.0286	2952	-0.29	0.7743
8	395.3(d)	<168 hours between restarts	3.4726	0.0740	222	.	.
9	395.3(d)	≥168 hours between restarts	3.4609	0.0738	220	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0117	0.0175	2700	0.67	0.5060

5.2.3.6 Karolinska Sleepiness Scale (KSS) in Restart Periods

Similar to findings for driver sleepiness ratings during duty periods, driver sleepiness ratings during restart periods were not related to provision use. As Table 27 shows, the KSS sleepiness scores were consistently near 3.6 across provisions. Table 27 also shows no statistically reliable differences in sleepiness as a function of provision used during restarts.

Table 27. Linear mixed-effect model: mean KSS ratings in restart periods by condition (rated by driver on a scale of 1 "extremely alert" to 9 "extremely sleepy").

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.6713	0.0843	350	.	.
2	395.3(c)	2-night restart (R2)	3.5849	0.0753	224	.	.
3	395.3(c)	>2-night restart (>R2)	3.6126	0.0750	221	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.0864	0.0468	4580	1.85	0.0648
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0587	0.0480	3882	1.22	0.2208
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.0277	0.0274	2579	-1.01	0.3134
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.0726	0.0453	4418	1.60	0.1095
8	395.3(d)	<168 hours between restarts	3.6019	0.0753	225	.	.
9	395.3(d)	≥168 hours between restarts	3.6001	0.0749	220	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0018	0.0262	3073	0.07	0.9461

As shown in Table 28, overall, drivers rated their sleepiness higher during the restart period than during duty periods ($p < 0.0001$).

Table 28. Linear mixed model for the KSS: mean difference of duty period – restart period.

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	-0.1487	0.01151	3009	-12.93	<0.0001*

*Statistically significant difference at .05 level.

5.2.3.7 Driver-rated Fatigue in Duty Periods

Table 29 displays the results for fatigue scale (FS) ratings during duty periods. The FS ranged from 1 "alert" to 5 "tired." As shown in the table, drivers' use of provision options within Section 395.3(c) and 395.3(d) had no effect on their FS ratings during duty periods.

Table 29. Linear mixed-effect model: mean driver-rated fatigue ratings in duty periods by provision condition (fatigue rated on a fatigue scale where 1 is "alert" and 5 is "tired").

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	1.9437	0.0468	284	.	.
2	395.3(c)	2-night restart (R2)	1.9440	0.0440	222	.	.
3	395.3(c)	>2-night restart (>R2)	1.9311	0.0442	226	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0003	0.0201	2855	-0.01	0.9883
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0126	0.0213	2838	0.59	0.5555
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0129	0.0131	2605	0.98	0.3276
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.0061	0.0196	2875	0.31	0.7547
8	395.3(d)	<168 hours between restarts	1.9418	0.0441	224	.	.
9	395.3(d)	≥168 hours between restarts	1.9335	0.0439	221	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hour between restarts	0.0083	0.0121	2662	0.69	0.4927

5.2.3.8 Driver-rated Fatigue in Restart Periods

Although drivers' ratings of fatigue did not vary by provision use in duty periods (Table 29), some provision-related differences were found in restart periods. These are shown in Table 30. During duty periods, drivers rated themselves as moderately more fatigued during a 1-night restart than during a 2-night restart (Row 4, $p = 0.0491$); more fatigued during a 1-night restart than during a more-than-2-night restart (Row 5, $p = 0.0438$); and more fatigued during a 1-night restart compared to the average of the 2-night restart and the more-than-2-night restart (Row 7, $p = 0.0371$). Section 395.3(d) options were not associated with differences in drivers' fatigue during restarts.

Table 30. Linear mixed-effect model: mean driver-rated fatigue in restart periods by provision condition (on a fatigue scale where 1 is "alert" and 5 is "tired").

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	2.0127	0.0510	374	.	.
2	395.3(c)	2-night restart (R2)	1.9542	0.0450	229	.	.
3	395.3(c)	>2-night restart (>R2)	1.9509	0.0448	226	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 - R2)	0.0585	0.0297	4177	1.97	0.0491*
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.0618	0.0306	3642	2.02	0.0438*
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.0033	0.0178	2564	0.18	0.8537
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.0601	0.0288	4062	2.09	0.0371*
8	395.3(d)	<168 hours between restarts	1.9625	0.0450	230	.	.
9	395.3(d)	≥168 hours between restarts	1.9504	0.0447	224	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0121	0.0169	2962	0.72	0.4746

*Statistically significant difference at .05 level.

Table 31 shows the result of a comparison of drivers' fatigue ratings between duty periods and restart periods. Fatigue ratings during restarts were reliably higher than fatigue ratings during duty periods (p = 0.0005).

Table 31. Linear mixed model for driver-rated fatigue: mean difference of duty period – restart period (maximum likelihood used instead of restricted maximum likelihood to obtain convergence).

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = 0
Duty Period – Restart Period	-0.0239	0.0069	3009	-3.48	0.0005

*Statistically significant difference at .05 level.

5.2.3.9 Fatigue-related False Safety Triggers in Duty Periods

The last fatigue outcome, fatigue-related false safety triggers, was only relevant to duty periods. A total of 2,988 sampling units among 226 drivers were available for this analysis. However, as with the fatigue-related SCEs, the fatigue-related false safety triggers did not result in a sufficiently substantial data set for statistical analysis. In many cases, this was due to inadequate time (8 seconds) to use established criteria to determine if the driver was fatigued. Thus, there were too few fatigue-related false safety triggers to sufficiently evaluate whether there were differences for each provision. (See Section 4.5 for details.)

5.2.4 Health Outcomes: Mixed-effect Model

Health outcomes included the following variables for duty periods and restart periods: stress, sleep duration per 24 hours, and driver-rated sleep quality. A total of 3,287 sampling units among 235 drivers were available for evaluation of stress and sleep quality. To evaluate sleep duration per 24 hours, a total of 1,964 sampling units among 202 drivers and 2,539 sampling units among 210 drivers were used for restart periods and duty periods, respectively (missing actigraph data and sleep diary entries reduced the number of drivers and sampling units).

5.2.4.1 Driver Stress Ratings in Duty Periods

A 5-point subjective rating stress scale (SS), where 1 indicated “not stressed,” and 5 indicated “very stressed,” was used to obtain information on drivers’ perceptions of their stress levels during their duty periods. Table 32 shows the mean SS ratings for each provision and the results of the statistical analyses. As Table 32 shows, there were no statistically significant differences in the use of the provisions during the duty periods.

Table 32. Linear mixed-effect model: mean driver-rated stress in duty periods by provision condition on the SS (1 = “not stressed” and 5 = “very stressed”).

Row	Section Relevance	Variable	Predicted Means or Predicted Mean Differences	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	1.5414	0.0472	319	.	.
2	395.3(c)	2-night restart (R2)	1.5632	0.0432	227	.	.
3	395.3(c)	>2-night restart (>R2)	1.5758	0.0435	233	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0218	0.0238	2916	-0.92	0.3589
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0344	0.0252	2921	-1.36	0.1731
6	395.3(c)	Difference between 2-night restart and>2-night restart (R2 minus >R2)	-0.0126	0.0158	2787	-0.80	0.4252
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0281	0.0232	2935	-1.21	0.2261
8	395.3(d)	<168 hours between restarts	1.5711	0.0434	230	.	.
9	395.3(d)	≥168 hours between restarts	1.5666	0.0432	226	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0045	0.0145	2786	0.31	0.7575

5.2.4.2 Driver Stress Ratings in Restart Periods

Similar to the findings for duty periods (Table 32), the results for stress ratings from restart periods shown in Table 33 reveal no differences in drivers' ratings as a function of provision use during the restart period.

Table 33. Linear mixed-effect model: mean driver-rated stress in restart periods by provision condition on the SS (1 = "not stressed" and 5 = "very stressed").

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	1.4020	0.0445	413	.	.
2	395.3(c)	2-night restart (R2)	1.4204	0.0385	235	.	.
3	395.3(c)	>2-night restart (>R2)	1.4356	0.0387	240	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0184	0.0281	3350	-0.66	0.5121
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0336	0.0295	3187	-1.14	0.2546
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.0152	0.0181	2733	-0.84	0.3999
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0260	0.0274	3329	-0.95	0.3417
8	395.3(d)	<168 hours between restarts	1.4369	0.0386	238	.	.
9	395.3(d)	≥168 hours between restarts	1.4180	0.0383	231	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0189	0.0168	2877	1.12	0.2615

Analyses were then conducted to determine if there were differences in the SS ratings between the duty period and the restart period. As shown in Table 34, the result of this analysis was statistically significant and found that drivers' stress ratings were moderately—but reliably—higher during duty periods than during restart periods ($p < 0.0001$).

Table 34. Linear mixed model for driver-rated SS: mean difference of duty period – restart period (maximum likelihood used instead of restricted maximum likelihood to obtain convergence).

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	0.1755	0.0050	3009	35.02	<0.0001*

*Statistically significant difference at .05 level.

5.2.4.3 *Sleep Duration in Duty Periods*

Table 35 displays the means and analyses for sleep per 24 hours during duty periods. It is noteworthy that across all provisions, mean sleep was approximately 6.5 hours during the duty period. The analyses did not find statistically significant differences in the use of the provisions during duty periods.

Table 35. Linear mixed-effect model: mean hours of sleep per 24 hours in duty periods by provision condition.

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	6.4824	0.0918	374	.	.
2	395.3(c)	2-night restart (R2)	6.5860	0.0793	214	.	.
3	395.3(c)	>2-night restart (>R2)	6.5887	0.0804	226	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.1036	0.0590	2374	-1.76	0.0793
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.1063	0.0630	2388	-1.69	0.0918
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.0027	0.0404	2377	-0.07	0.9472
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.1050	0.0576	2382	-1.82	0.0686
8	395.3(d)	<168 hours between restarts	6.5501	0.0798	219	.	.
9	395.3(d)	≥168 hours between restarts	6.5770	0.0792	213	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0269	0.0370	2358	-0.73	0.4671

5.2.4.4 *Sleep Duration in Restart Periods*

Table 36 shows drivers' mean hours of sleep per 24 hours during the restart periods. As shown, Section 395.3(c) affected sleep duration during restarts. The analysis of sleep duration per 24 hours did not find statistically significant differences between 1- and 2-night restarts. However, sleep duration per 24 hours was longer during 1-night restarts compared to more-than-2-night restarts ($p < 0.0001$), and longer than during the average of the 2-night restart and the more-than-2-night restart ($p = 0.01$). The 2-night restart averaged higher sleep durations than the more-than-2-night restart ($p < 0.0001$), because the more nights drivers had for restart, the lower the sleep amount per 24 hours (an indication of dissipating sleep debt across nights of recovery). In addition, Section 395.3(d) was related to sleep duration per 24 hours during restart. When restart occurred at or after 168 hours, sleep duration per 24 hours was longer ($p = 0.0457$). This pattern was consistent with the reduction of sleep pressure when recovering from a cumulative sleep debt.[59] However, this difference was small compared to the marked difference between sleep during duty periods (Table 35) and sleep during restart periods (Table 36).

Table 36. Linear mixed-effect model: mean hours of sleep per 24 hours in restart periods by provision condition.

Row	Section Relevance	Variable	Predicted Means or Predicted Mean Differences	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	8.8580	0.1286	664	.	.
2	395.3(c)	2-night restart (R2)	8.8330	0.0939	228	.	.
3	395.3(c)	>2-night restart (>R2)	8.3186	0.0993	280	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	0.0249	0.1118	1866	0.22	0.8235
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	0.5394	0.1203	1892	4.48	<0.0001*
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	0.5144	0.0777	1877	6.62	<0.0001*
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	0.2822	0.1095	1881	2.58	0.0100*
8	395.3(d)	<168 hours between restarts	8.5651	0.0961	245	.	.
9	395.3(d)	≥168 hours between restarts	8.7095	0.0948	238	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.1445	0.0723	1854	-2.00	0.0457*

*Statistically significant difference at .05 level.

As shown in Table 37, mean sleep per 24 hours during restart periods was 2 hours and 11 minutes longer (-2.1936 hours, $p < 0.0001$). This is a very large difference that was present regardless of the provision options used for restart relative to Sections 395.3(c) and 395.3(d).

Table 37. Linear mixed model for mean sleep per 24 hours: mean difference of duty period – restart period.

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	-2.1936	0.0387	4316	-56.62	<0.0001*

*Statistically significant difference at .05 level.

5.2.4.5 Sleep Duration by Time of Day

The evaluation of sleep obtained at different times of day is presented below only as descriptive data relative to the provisions. The period from 8 p.m. to 8 a.m. was used to define the nocturnal portion of the day, which is the phase when humans are biologically programmed to sleep. The amount of time drivers were sleeping during this 12-hour phase was then calculated as a percentage of their total time sleeping, to obtain an unadjusted estimate of the extent to which the use of different provision options resulted in sleep that was appropriately timed to the biological phase for sleep.

Sleep timing relative to Section 395.3(c)

During their duty periods, drivers who used a 1-night restart obtained approximately 56 percent of their duty sleep during the nocturnal period from 8 p.m. to 8 a.m. The comparable percentages for drivers who had a 2-night or more-than-2-night restart were 78 percent and 84 percent, respectively, during their duty periods. During restart periods, drivers who used a 1-night restart obtained 71 percent of their sleep between 8 p.m. and 8 a.m., compared to 83 percent and 88 percent for drivers who used a 2-night restart and a more-than-2-night restart, respectively. This suggests that drivers who opt for 1-night restarts were more likely to obtain sleep during the diurnal portion of the day than drivers who elected to restart with 2 or more nights of sleep.

Sleep timing relative to Section 395.3(d)

During their duty periods, drivers who used a restart in less than 168 hours obtained approximately 75 percent of their duty sleep during the nocturnal period from 8 p.m. to 8 a.m. Those who took a restart after 168 hours or more had approximately 79 percent of their duty sleep during this nocturnal window. During restarts, those who took a restart in less than 168 hours had 82 percent of their restart sleep during the nocturnal period from 8 p.m. to 8 a.m., and those who took a restart at or after 168 hours had 84 percent of their restart sleep in this nocturnal window.

Overall, sleep during the nocturnal portion of the day was more likely during restart periods than during duty periods. Among restart options, 1-night restarts were associated with the lowest proportion of time sleeping during the nocturnal time (8 p.m. – 8 a.m.), when the body is biologically programmed to sleep.

5.2.4.6 Sleep Quality in Duty Periods

Drivers provided subjective quality ratings for their sleep periods. The predicted means and analyses of these data are shown in Table 38. The use of the provisions had no relationship to drivers' sleep quality ratings during duty periods.

Table 38. Linear mixed-effect model: mean driver-rated sleep quality ratings in duty periods by provision (1= poor sleep quality, 5=highest sleep quality).

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.7540	0.0520	272	.	.
2	395.3(c)	2-night restart (R2)	3.7871	0.0482	202	.	.
3	395.3(c)	>2-night restart (>R2)	3.7957	0.0485	207	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 minus R2)	-0.0331	0.0247	2602	-1.34	0.1797
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 minus >R2)	-0.0416	0.0262	2608	-1.59	0.1122
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 minus >R2)	-0.0085	0.0166	2600	-0.52	0.6066
7	395.3(c)	Difference between 1-night restart and the average of a 2-night and >2-night restart	-0.0374	0.0240	2606	-1.55	0.1204
8	395.3(d)	<168 hours between restarts	3.7914	0.0483	204	.	.
9	395.3(d)	≥168 hours between restarts	3.8037	0.0481	201	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	-0.0123	0.0152	2591	-0.81	0.4181

5.2.4.7 Sleep Quality in Restart Periods

Table 39 shows drivers' sleep quality ratings. Sleep quality ratings were associated with provision use during restarts for Section 395.3(c). Sleep quality ratings were lower during a 1-night restart relative to a 2-night restart (p = 0.0114), relative to a more-than-2-night restart (p = 0.0080), and relative to the average of the 2-night restart and the more-than-2-night restart (p = 0.0061). Restart options in Section 395.3(d) had no relationship to sleep quality.

Table 39. Linear mixed-effect model: mean driver-rated sleep quality ratings in restart periods by provision (1= poor sleep quality, 5=highest sleep quality).

Row	Section Relevance	Variable	Predicted Mean or Predicted Mean Difference	Standard Error	DF	T-value	P-value for Test of Mean Difference = Zero
1	395.3(c)	1-night restart (R1)	3.7882	0.0520	315	.	.
2	395.3(c)	2-night restart (R2)	3.8626	0.0465	203	.	.
3	395.3(c)	>2-night restart (>R2)	3.8711	0.0469	211	.	.
4	395.3(c)	Difference between 1-night and 2-night restarts (R1 – R2)	-0.0745	0.0294	2585	-2.53	0.0114*
5	395.3(c)	Difference between 1-night restart and >2-night restart (R1 - >R2)	-0.0830	0.0313	2596	-2.65	0.0080*
6	395.3(c)	Difference between 2-night restart and >2-night restart (R2 - >R2)	-0.0085	0.0198	2589	-0.43	0.6688
7	395.3(c)	Difference between 1-night restart and the average of a 2-night restart and >2-night restart	-0.0787	0.0287	2591	-2.74	0.0061*
8	395.3(d)	<168 hours between restarts	3.8625	0.0467	207	.	.
9	395.3(d)	≥168 hours between restarts	3.8608	0.0464	202	.	.
10	395.3(d)	Difference between <168 hours between restarts and ≥168 hours between restarts	0.0017	0.0182	2576	0.09	0.9262

*Statistically significant difference at .05 level.

As shown in Table 40, sleep quality ratings were significantly lower during duty periods than during restart periods ($p < 0.0001$).

Table 40. Linear mixed model for mean sleep quality rating: mean difference of duty period – restart period.

Comparison	Predicted Mean Difference	Standard Error	DF	T-value	P-value for Mean Difference = Zero
Duty Period – Restart Period	-0.0851	0.0108	5336	-7.86	<0.0001

*Statistically significant difference at .05 level.

5.3 RESULTS OF WITHIN-DRIVER ANALYSES FOR EFFECTS OF PROVISIONS

In addition to the mixed-model analyses, the research team capitalized on the fact that a substantial number of drivers opted to use 1-night and 2-night restarts, and/or to take restarts in less than 168 hours or in at least 168 hours. This provided another opportunity to conduct simple within-subjects analyses (parametric and nonparametric) to determine the effects of the restart provisions on the study outcomes. Table 41, Table 42, and Table 43 display these within-subjects comparisons. The direction of the comparison can be seen by which percentage is larger, the positive or the negative. The sign-test is very robust and does not depend on any distribution for its validity. This is the primary test for the within-subjects analyses (it is non-parametric). If the paired t-test results are very different than the sign-test results, the sign-test should be interpreted. However, comparisons with a marginal sign-test coupled with a significant paired t-test should be interpreted.

Table 41 displays results for Section 395.3(d). It confirms the mixed-model results that PVT-B lapses in restarts were more frequent during restart periods when restarts were taken in at least 168 hours as compared to less than 168 hours ($p = 0.026$), and that mean sleep duration in restarts was higher during restart periods when they were taken in at least 168 hours as compared to less than 168 hours ($p = 0.0006$).

Table 42 provides within-driver results relevant to Section 395.3(c) for a 1-night versus 2-night restart. It confirms the mixed-model results that during the restart period, drivers rated their sleep quality higher during a 2-night restart than during a 1-night restart ($p = 0.047$). There is also a finding that drivers' ratings of stress during the restart period were higher during the 2-night restart than during the 1-night restart ($p = 0.007$).

Table 43 displays the within-subjects comparisons for a 1-night restart compared to a 2-night or more-than-2-night restart. It confirms there was greater driving time with a 1-night restart ($p = 0.042$) and longer PVT-B response speed ($p = 0.046$) in restarts during a 1-night restart compared to a more-than-2-night restart. There were fewer PVT-B lapses ($p = 0.036$) during restarts, drivers rated their difficulty of driver lower ($p = 0.014$), and drivers' ratings of stress during restarts were lower ($p = 0.003$) during a 1-night restart compared to a more-than-2-night restart.

To summarize, the within-subjects analyses provide a different approach to analyzing the data where the data are limited to only drivers that experienced both provisions. This is a powerful statistical approach as it controls for individual error variance because the same drivers are included in both provisional options. The results from these analyses confirm some of the key results of the full mixed-model analyses presented earlier. Therefore, two different approaches to analyze the data were conducted and the results from each approach were similar.

Table 41. Within-driver differences for restart <168 hours since last restart minus restart ≥168 hours since last restart.

Outcome	Pairs	Number positive	Percent positive	Number negative	Percent negative	Number zeros	Mean Difference	Standard Deviation	Min	Max	Sign Test p-value	Paired T p-value
Driving Hours per Day	201	92	45.8	109	54.2	0	-0.170	1.098	-7.934	2.266	0.259	0.167
Work Hours per Day	201	90	44.8	111	55.2	0	-0.130	1.325	-11.197	4.707	0.158	0.167
SCE Rate per 100 Hours	201	81	40.3	85	42.3	35	-0.059	5.279	-17.739	51.433	0.816	0.875
PVT-B Mean 1/RT in NR(t)	193	99	51.3	94	48.7	0	0.014	0.183	-1.329	1.126	0.774	0.273
PVT-B Mean 1/RT in R(t)	191	107	56.0	84	44.0	0	0.026	0.198	-0.906	1.016	0.111	0.070
PVT-B Total Lapses in NR(t)	193	93	48.2	100	51.8	0	-0.271	1.948	-12.091	6.080	0.666	0.055
PVT-B Total Lapses in R(t)	191	84	44.0	107	56.0	1	-0.400	2.471	-15.292	6.682	0.111	0.026*
Difficulty of Drive	192	92	47.9	83	43.2	17	0.001	0.259	-2.092	1.006	0.546	0.978
Safety Hazards	192	97	50.5	84	43.8	11	-0.007	0.289	-2.738	0.501	0.373	0.721
Stress Scale in NR(t)	193	98	50.8	84	43.5	11	-0.008	0.245	-1.219	1.493	0.335	0.640
Stress Scale in R(t)	191	82	42.9	85	44.5	24	0.012	0.361	-2.463	2.683	0.877	0.649
Fatigue Scale in NR(t)	193	100	51.8	88	45.6	5	0.008	0.223	-0.708	1.442	0.423	0.604
Fatigue Scale in R(t)	191	90	47.1	95	49.7	6	-0.015	0.293	-1.800	0.618	0.769	0.472
KSS Sleepiness in NR(t)	193	97	50.3	95	49.2	1	-0.004	0.399	-2.727	1.722	0.943	0.893
KSS Sleepiness in R(t)	191	88	46.1	102	53.4	1	-0.073	0.545	-3.667	1.118	0.346	0.065
Mean Sleep Quality in NR(t)	175	82	46.9	84	48.0	9	-0.001	0.188	-0.677	0.571	0.938	0.920
Mean Sleep Quality in R(t)	174	83	47.7	76	43.7	15	0.003	0.309	-1.115	2.000	0.634	0.891
Mean Sleep in NR(t)	166	93	56.0	73	44.0	0	0.017	0.612	-1.895	2.553	0.140	0.727
Mean Sleep in R(t)	146	52	35.6	94	64.4	0	-0.184	1.291	-5.189	7.221	0.0006*	0.087

*Statistically significant difference at .05 level.

NR(t) = Duty Period; R(t) = Restart Period

Table 42. Within-driver differences for 1-night restarts minus 2-night restarts.

Outcome	Pairs	Number positive	Percent positive	Number negative	Percent negative	Number zeros	Mean Difference	Standard Deviation	Min	Max	Sign Test p-value	Paired T p-value
Driving Hours per Day	129	73	56.6	56	43.4	0	0.178	1.252	-3.012	5.057	0.159	0.108
Work Hours per Day	129	68	52.7	61	47.3	0	0.198	1.635	-6.570	4.911	0.598	0.171
SCE Rate per 100 Hours	129	43	33.3	56	43.4	30	-0.672	6.059	-51.598	16.387	0.228	0.210
PVT-B Mean Reciprocal RT in NR(t)	120	61	50.8	59	49.2	0	0.021	0.271	-0.779	1.565	0.927	0.408
PVT-B Mean Reciprocal RT in R(t)	118	63	53.4	55	46.6	0	0.029	0.335	-1.059	1.675	0.520	0.351
PVT-B Total Lapses in NR(t)	120	58	48.3	62	51.7	0	-0.229	3.218	-15.009	8.433	0.784	0.436
PVT-B Total Lapses in R(t)	118	49	41.5	68	57.6	1	-0.264	4.521	-15.444	16.729	0.096	0.527
Difficulty of Drive	120	45	37.5	62	51.6	13	-0.010	0.305	-0.864	1.203	0.122	0.733
Safety Hazards	120	54	45.0	57	47.5	9	-0.032	0.371	-1.099	1.190	0.850	0.347
Stress Scale in NR(t)	120	50	41.7	62	51.9	8	-0.025	0.383	-1.194	1.634	0.299	0.475
Stress Scale in R(t)	118	37	31.4	65	55.1	16	-0.020	0.385	-1.250	1.909	0.007*	0.574
Fatigue Scale in NR(t)	120	61	50.8	59	49.2	0	0.010	0.285	-0.841	1.063	0.927	0.649
Fatigue Scale in R(t)	118	52	44.1	57	48.3	9	0.019	0.400	-1.083	1.600	0.702	0.613
KSS in NR(t)	120	54	45.0	65	54.2	1	-0.019	0.491	-2.015	1.583	0.359	0.675
KSS in R(t)	118	57	48.3	59	50.0	2	-0.033	0.627	-2.711	2.148	0.926	0.564
Mean Sleep Quality in NR(t)	109	44	40.4	55	50.5	10	-0.061	0.358	-1.486	1.003	0.315	0.080
Mean Sleep Quality in R(t)	108	44	40.7	50	46.3	14	-0.099	0.516	-2.438	2.222	0.606	0.047*
Mean Sleep in NR(t)	104	45	43.3	59	56.7	0	-0.115	0.812	-2.285	2.903	0.202	0.151
Mean Sleep in R(t)	92	48	52.2	44	47.8	0	-0.030	1.774	-7.170	3.783	0.755	0.874

*Statistically significant difference at .05 level.

NR(t) = Duty Period; R(t) = Restart Period

Table 43. Within-driver differences for 1-night restart minus 2-night and more-than-2-night restarts.

Outcome	Pairs	Number positive	Percent positive	Number negative	Percent negative	Number zeros	Mean Difference	Standard Deviation	Min	Max	Sign Test p-value	Paired T p-value
Driving Hours per Day	132	75	56.8	57	43.2	0	0.225	1.2621	-2.973	5.577	0.139	0.042*
Work Hours per Day	132	75	56.8	57	43.2	0	0.233	1.4592	-5.218	5.637	0.139	0.069
SCE Rate per 100 Hours	132	41	31.1	66	50.0	24	-0.174	3.5825	-12.573	18.362	0.020	0.578
PVT-B Mean Reciprocal RT in NR(t)	123	60	48.8	63	51.2	0	0.024	0.2395	-0.674	1.280	0.857	0.260
PVT-B Mean Reciprocal RT in R(t)	123	73	59.4	50	40.7	0	0.054	0.3166	-0.835	1.435	0.046*	0.062
PVT-B Total Lapses in NR(t)	123	60	48.8	63	51.2	0	-0.302	2.9256	-15.009	6.196	0.857	0.255
PVT-B Total Lapses in R(t)	123	49	39.8	73	59.4	1	-0.442	4.2184	-18.333	12.952	0.036*	0.247
Difficulty of Drive	123	43	35.0	70	56.9	10	-0.005	0.2831	-0.750	1.087	0.014*	0.831
Safety Hazards	123	55	44.7	61	49.6	7	-0.029	0.3426	-1.055	1.146	0.643	0.355
Stress Scale in NR(t)	123	52	42.3	65	52.9	6	-0.013	0.3590	-1.215	1.658	0.267	0.691
Stress in R(t)	123	39	31.7	70	56.9	14	-0.016	0.3609	-1.439	1.274	0.003*	0.633
Fatigue Scale in NR(t)	123	64	52.0	59	48.0	0	0.012	0.2842	-1.125	0.832	0.719	0.649
Fatigue Scale in R(t)	123	61	49.5	61	49.5	1	0.008	0.4165	-1.363	1.474	1.000	0.822
KSS in NR(t)	123	57	46.3	66	53.7	0	-0.009	0.4406	-1.460	1.620	0.471	0.820
KSS in R(t)	123	62	50.4	59	48.0	2	-0.056	0.6713	-2.674	2.684	0.856	0.353
Mean Sleep Quality in NR(t)	111	49	44.1	57	51.4	5	-0.059	0.3568	-1.486	1.091	0.497	0.085
Mean Sleep Quality in R(t)	110	47	42.7	54	49.1	9	-0.107	0.4917	-1.936	2.289	0.551	0.025*
Mean Sleep in NR(t)	107	49	45.8	58	54.2	0	-0.053	0.8390	-2.339	3.330	0.439	0.514
Mean Sleep in R(t)	95	52	54.7	43	45.3	0	0.102	1.6983	-5.041	3.986	0.412	0.560

*Statistically significant difference at .05 level.

NR(t) = Duty Period; R(t) = Restart Period

5.4 POOLABILITY ANALYSES FOR THE EFFECTS OF PROVISIONS

As stated in the statute, "The study shall include fleets of all sizes (i.e., small, medium, and large) and operations (including long-haul, regional, and short-haul) in various sectors of the industry (including flat-bed, refrigerated, tank, and dry-van) to the extent practicable. Thus, a third set of analyses were conducted as part of this study. Although the study was not powered to compare outcome differences associated with the two provisions as a function of type of operation or fleet size, the study plan indicated these differences would be assessed in descriptive "poolability" analyses using appropriate summary statistics. The sampling plan required representativeness of industry elements diverse in company size, type of operation, and industry sector. This forms the basis for the poolability analysis to evaluate whether restart provision effects were consistent across subsets of the trucking operations represented in the study. Specific contrasts are statistically pooled over fleet sizes in order to compare among types of operations. In general, the focus of comparisons across sampling strata was to evaluate whether it can be confidently concluded that results (relative to restart schedules) compare across drivers from different fleet sizes and different types of operations.

Tables 45–80 in Appendix L present the results of the poolability analyses. The takeaway message from the poolability analyses is that the results show that diversity in the industry, relative to carrier size, operations, and industry sector, does not differ in the use of the provisions and their effects on different outcome domains. A notable exception is found in Table 75 on sleep time during restarts. Drivers from large carriers (estimate = 0.5133) and regional carriers (estimate = 0.6862, $p = 0.0006$) appear to get less sleep during 2-night restarts than during 1-night restarts, but the opposite is the case for medium carriers (estimate = -0.4757, $p = 0.0158$) and small carriers (estimate = -0.8713, $p = 0.0042$). This is evidence of a qualitative interaction between industry segment and provision use.

Another interesting observation is found in Table 69, which displays the results for the duration of restart as determined through ELD data. Not surprisingly, all segments indicate a longer restart when drivers take a 2-night restart relative to a 1-night restart. However, the difference in the length of the restart appears to be two- to three-fold across segments, with shorter restarts occurring in small companies, in tanker operations, and in long-haul operations. In contrast, longer restarts occurred in large companies, short-haul operations, and flatbed trailers.

It is recognized that some of the differences in the poolability analyses are due to chance, given the number of comparisons. The tables should be used to look for large qualitative interactions, such as in Table 69 and Table 75, where one segment is significantly negative while another is significantly positive. These poolability analyses were designed to add detail concerning the possibility of variations in the overall outcomes by segment. Other analyses of the data and future studies will be necessary to shed further light on how diversity of trucking operations affects the utility and impact of the restart provisions.

6. CONCLUSIONS, LIMITATIONS, AND FUTURE CONSIDERATIONS

6.1 SUMMARY OF RESULTS OF THE EFFECT OF SECTION 395.3(C) ON OUTCOMES

The mixed-effects model results presented in Tables 12–40 indicate that the use of the 1-night restart option versus the 2-night restart option in Section 395.3(c) had effects on some of the study outcomes, as did Section 395.3(d). However, the magnitude of the effects was modest compared to the overall benefit afforded by a restart. The results of this extensive naturalistic investigation of how CMV operators use Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, relative to operational, safety, fatigue, and health outcomes revealed both expected and unexpected findings in the four outcome domains.

6.1.1 Operational Outcomes

Drivers' mean driving hours per 24 hours in duty periods were as follows: 8.22 hours for drivers using a 1-night restart, 8.08 hours for drivers using a 2-night restart, and 8.00 hours for driver using a more-than-2-night restart. The mean driving hours per 24 hours in duty periods for drivers using the 1-night restart were significantly greater than they were for drivers using the more-than-2-night restart (t-value = 2.37, $p = 0.018$). Mean driving hours per 24 hours in duty periods were the same (8.06 hours) for drivers who had less than 168 hours between their restart periods and for drivers who had at least 168 hours between their restart periods.

Drivers' mean work hours per 24 hours in duty periods were as follows: 10.20 hours for drivers using a 1-night restart, 10.11 hours for drivers using a 2-night restart, and 9.98 hours for drivers using a more-than-2-night restart. Mean work hours per 24 hours in duty periods following a 1-night restart were significantly greater than mean work hours per 24 hours in duty periods following a more-than-2-night restart (t-value = 2.30, $p = 0.021$). Mean work hours per 24 hours in duty periods following a 2-night restart were also significantly greater than mean work hours per 24 hours in duty periods following a more-than-2-night restart (t-value = 2.14, $p = 0.033$). For drivers with less than 168 hours between restart periods, mean work hours per 24 hours in duty periods were 10.11; for drivers with at least 168 hours between restart periods, mean work hours per 24 hours in duty periods were 10.03.

6.1.2 Safety Outcomes

The primary safety outcomes were the rates of SCEs and fatigue-related SCEs per 100 hours instrumented driving time captured via OBMS. These included electronically-recorded hard braking, hard acceleration, swerves, contact with other objects, and driving in excess of posted speed limits. As shown in Table 16, the rates of SCEs per 100 hours instrumented driving time in duty periods were as follows: 0.34 for drivers using a 1-night restart, 0.37 for drivers using a 2-night restart, and 0.35 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods, the rate of SCEs per 100 hours instrumented driving time in duty periods was 0.36; for drivers with at least 168 hours between restart periods, the rate was 0.37.

The rates of fatigue-related SCEs per 100 hours instrumented driving time in duty periods were as follows: 0.00 for drivers using a 1-night restart, 0.01 for drivers using a 2-night restart, and 0.00 for drivers using a more-than-2-night restart. For drivers with less than 168 hours between restart periods and for drivers with at least 168 hours between restart periods, the rate of fatigue-related SCEs per 100 hours instrumented driving time in duty periods was 0.00.

6.1.3 Fatigue Outcomes

Driver fatigue was objectively assessed by measuring driver alertness performance on daily iterations of an electronic PVT-B performance test, and subjectively assessed via driver ratings of fatigue and sleepiness. Driver ratings of fatigue were higher during 1-night restarts ($p = 0.0371$), but not during duty periods following 1-night restarts. In both restart and duty periods, PVT-B response speed was slowest in drivers who took restarts that were longer than 2 nights. Relative to Section 395.3(d), PVT-B response speed was slower and PVT-B lapses were more frequent when drivers restarted at 168 hours or more compared to less than 168 hours. This was the case for PVT-B performance in both duty periods and restart periods (p values between 0.0503 and 0.0087, Tables 18, 19, 22, 23, and 24). This suggests that restarts taken after 168 or more hours reduce psychomotor vigilance performance due to cumulative fatigue. Consistent with this finding was the fact that drivers averaged more sleep during restarts that occurred in 168 hours or more than they did during restarts that occurred in less than 168 hours ($p = 0.0457$, Table 36).

Other evidence that drivers were consistently fatigued by the time they took restarts, regardless of the provision used, derives from comparisons of drivers' responses during duty periods compared to their responses during restarts. In addition to slower PVT-B responses ($p < 0.0001$, Table 20) during restart periods compared to duty periods, drivers had a higher rate of PVT-B lapses of attention ($p < 0.0001$, Table 25); higher sleepiness ratings ($p < 0.0001$, Table 28); and higher fatigue ratings ($p < 0.0001$, Table 31) during restarts than during duty periods. Consistent with this evidence of behavioral fatigue is the fact that drivers averaged more than a 2-hour increase in sleep duration during restart compared to duty periods, regardless of the provision they used to restart.

Drivers averaged a statistically-predicted mean of greater than 8.5 hours of sleep per 24 hours during restarts of 1 or 2 nights and regardless of the 168-hour rule used. This is approximately 30 percent more sleep than they routinely obtained each day during duty periods ($p < 0.0001$, Table 37). Their statistically-predicted mean sleep time on duty days was less than 6.6 hours per 24 hours, which is below the recommended 7-hour threshold for daily sleep to promote health (as recently published by the American Academy of Sleep Medicine and the Sleep Research Society).[60,61,62] Collectively, the data suggest that drivers developed a cumulative sleep debt during duty periods, which increased their biological sleep propensity (i.e., the tendency to fall asleep and sleep longer) during restarts. This outcome would be consistent with drivers also reporting more subjective fatigue and sleepiness, and manifesting reduced PVT-B performance during restarts as compared to duty periods. There is little known scientifically about the potential effects of repeated cycling through sleep restriction and sleep extension. Although this study suggests the sleep restriction-recovery differential is large (and common in the trucking industry), the health and performance effects of repeated cycling through sleep restriction need to be better understood in this cohort.

6.1.4 Health Outcomes

The value of restarts for increasing needed sleep time in drivers was evident in the results, but there also was evidence that restart sleep was perceived as better by the drivers. Drivers rated restart sleep to be of higher quality than sleep during duty periods ($p < 0.0001$, Table 40). Both adequate sleep duration and sleep quality are essential aspects of sleep health. It is noteworthy that relative to Section 395.3(c), drivers rated 2-night restarts to be of higher sleep quality than 1-night restarts ($p < 0.0114$, Table 39). The provisions did not affect drivers' ratings of stress, but drivers rated their stress higher during duty periods than during restart periods ($p < 0.0001$, Table 34). Therefore, restart periods served to mitigate driver fatigue, sleep loss and stress.

6.2 RESULTS RELATIVE TO FEDERAL SECTIONS 395.3(C) AND 395.3(D)

The use of 1-night and 2-night restarts, as well as more-than-2-night restarts, was expected, as was the additional sleep time the restart afforded drivers for recovery from work fatigue and reduced sleep time when working. The limited number of effects on duty periods from the type of restart used for each provision was unexpected. For example, sleep time was not different between the restart provisions during duty periods. On the other hand, drivers' fatigue ratings were higher during 1-night restarts relative to 2-night and more-than-2-night restarts (statistically reliable differences). Drivers' ratings of sleep quality during 1-night restarts were lower than during 2-night and more-than-2-night restarts (statistically reliable differences).

6.2.1 1-Night Restarts and Restarts Taken in 168 Hours or More

The slightly elevated subjective fatigue during 1-night restarts [Section 395.3(c)], and the slightly decreased PVT-B performance during both restart and duty periods associated with restarts greater than or equal to 168 hours [Section 393.5(d)], are consistent with an elevated sleep drive when these provisions are used. This was also evident in the fact that drivers obtained more sleep per 24 hours during the 1-night restart compared to the more-than-2-night restart ($p < 0.0001$), and more sleep when restarting at or after 168 hours than before 168 hours ($p = 0.0457$). Thus it appears that greater fatigue induced by these two options in the provisions is mitigated in part by somewhat greater sleep amounts during restart (Table 36).

Although of modest size, these reliable differences were found even when 1-night restarts were compared to the average of all restarts greater than 1 night. This suggests that relative to Section 395.3(c), restarts of 2 or more nights may result in subjectively better quality sleep and less fatigue relative to 1-night restarts. On the other hand, these modest subjective differences in the restart periods had no relationship to fatigue ratings and PVT-B performance during duty periods, which did not vary by how Section 395.3(c) was used.

The results also suggest that restarting when reaching 168 hours or more [Section 395.3(d)] resulted in greater subjective and objective indicators of fatigue. Thus, relative to Section 395.3(d), restarting in less than 168 hours was associated with faster PVT-B response times and fewer PVT-B lapses of attention during both restart periods and subsequent duty periods (again, these were modest but statistically reliable differences). Sleep duration per 24 hours was also longer when the restart was taken at or after 168 hours. These findings suggest that drivers experienced modest but reliable decreases in behavioral alertness for restarts that occurred at or after 168 hours [Section 395.3(d)].

Collectively, the data suggest that greater fatigue can be expected when drivers utilize the 1-night restart and take a restart in 168 hours or more. It is possible that a restart period of extended sleep can compensate for the cumulative sleep loss (sleep debt) from repeated duty days of reduced sleep. However, the long-term health and/or performance consequences of this pattern are not clear. There is a need to determine how to reduce some of the cumulative sleep debt of drivers by increasing duty day sleep time. Even small increments of 20–30 minutes per day may be beneficial for health and performance.

6.3 CONCLUSIONS

What was evident in the study results was the markedly increased sleep time afforded by the restarts relative to sleep during work weeks. Sleep time per 24 hours was increased by more than 2 hours from duty time amounts. This kind of differential between sleep duration when working and sleep duration when off duty also has been found in three studies(63,64,65) over the past 10 years (see Appendix A) that have used actigraphy to track sleep in CMV operators during duty periods and restart or off-duty periods—although the present data set is by far the largest collected on this topic. The consistency of the finding that sleep during duty periods is markedly less than sleep on off-duty days (including restarts) in CMV operators should not be ignored relative to the provisions or to future studies. There is extensive scientific evidence that inadequate sleep is a risk factor for many common health conditions (e.g., obesity, diabetes, and hypertension) as well as errors and accidents. As noted above, a recent comprehensive consensus report from the American Academy of Sleep Medicine and the Sleep Research Society by a group of scientists who used a modified RAND Appropriateness Method to conclude that "insufficient sleep" involves sleeping less than 7 hours per day. The CMV drivers who participated in this study average below that level on their working days.

The studies of sleep in CMV drivers, including the extensive data in this study, indicate that drivers obtain 6–6.5 hours of sleep a day for 4–7 days straight (i.e., up to 168-hour limit), before getting an opportunity to sleep long enough to recover from a sleep debt. There is a need to identify ways to increase the amount of time drivers spend sleeping within the 10 consecutive hours of off-duty time required by the current HOS regulations and avoid the risk that repeated chronic partial sleep loss poses to the health and safety of commercial truck drivers.

This study provided clear evidence that drivers were in need of sleep when they undertook a restart, and when they slept, it was much longer than when they slept on work/duty days. They were more fatigued; sleepier; less behaviorally alert on the PVT-B performance test; and less stressed during restarts than on duty days. Regardless of the restart provision used [Section 395.3(c) or Section 395.3(d)], there was evidence that the restart benefitted the ability of drivers to get some recovery from work stress, cumulative fatigue, and chronic sleep restriction. The drivers who participated in the study have made an important contribution to a continued evidenced-based approach to safe operations by CMV drivers.

6.4 STUDY LIMITATIONS

There are strengths and limitations of any research approach. The following is a description of the study's limitations.

6.4.1 Naturalistic Study Methodology

The Act directed FMCSA to conduct a CMV Driver Restart Study. Congress directed that within 90 days of enactment of The Act, "the Secretary shall initiate a naturalistic study of the operational, safety, health, and fatigue impacts of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, on commercial motor vehicle drivers." A naturalistic study of human behavior requires researchers to carefully observe and record behavior over a period of time in a natural setting, without applying an intervention, and while minimizing interference with the participants being monitored. This describes precisely how the CMV Driver Restart Study was conducted. It was fully observational without interventions or randomization of participants to different procedures. During the course of their participation, drivers directed their own schedules.

This approach limits the ability to determine the exact cause of a behavior (e.g., why a given restart provision was used by a CMV driver) and it prevents the control or measurement of variables that may influence behavior. Also, like other research methods, naturalistic studies can result in participants changing their behavior in a manner they think is desired by the researchers (i.e., demand characteristics), rather than behaving the way they normally would. These studies may also result in people changing behaviors by virtue of their awareness that they are being monitored. Finally, naturalistic studies may have a higher number of volunteer participants who feel they can tolerate the monitoring. They may differ in unknown ways from those who do not want to be monitored in a study, and therefore do not volunteer.

These factors may have been present in the study in varying degrees, but every effort was made to provide no guidance to participants as to how they conducted their work-rest activities and schedules. They were assured that their data was treated with strict confidentiality, and the only information provided to them was in relation to study compensation and use of study equipment.

6.4.2 Technology Use

The study used low-burden, minimally-obtrusive wrist actigraphy and smartphone app technologies to record drivers' sleep timing, duration, and quality. Physiological assessment of drivers' sleep using polysomnography would have provided a more precise measure of sleep timing, duration, and continuity, but it was beyond the scope, practicality, and cost of the study, and just as importantly, it would have risked altering the naturalistic study design by requiring the repeated application of electrodes for sleep recordings. In contrast, wrist actigraphy and electronic self-report of sleep times and quality are minimally intrusive, cost-effective, and demonstrated to provide reasonably good estimates of physiological sleep time and sleep quality. Therefore, these technologies were used in the study.

6.4.3 Fatigue Coding of Onboard Monitoring System Data

The method of determining driver fatigue from the OBMS data was to review the OBMS clips to look for, and score, overt fatigue by using procedures used in previous naturalistic driving studies. The technology vendor in this study used an 8-second pre-trigger duration, which was likely insufficient to reliably determine a driver's level of fatigue. However, it is unlikely that this limitation impacted the conclusions regarding fatigue, as the primary fatigue measure was the PVT-B test.

6.4.4 Seasonal Variance

Data acquisition for the study occurred from March through September in the northern hemisphere. Data were not acquired in the winter, when driving can pose greater weather-related risks. Driver participants came from across the United States, which further contributed to the representativeness of the study data. However, it is possible that had the study monitored driving in the winter, the drivers may have used the provisions in different ways.

6.4.5 Driver Data Self-report

Drivers were asked to provide their height and weight, as well as whether they had been diagnosed as having certain disorders (e.g., high blood pressure), and whether they were prescribed medications/therapies for those disorders. Self-report of such information is less reliable than physical measurements and confidential medical evaluations, which would have been beyond the scope of this naturalistic study. Consequently, the information that drivers provided regarding their physical and medical status may have limited accuracy.

6.5 OPPORTUNITIES FOR FUTURE RESEARCH

The analyses conducted in this study were focused on addressing the research questions that were directed in the statute. However, an important by-product of this study is a very rich data set that can be mined to answer many additional research questions that were not addressed in this report. This data set will provide the research community with a new opportunity to inform techniques and strategies that can be used to better the safety, health, and wellness of CMV drivers and the motoring public. This public-use dataset will provide the opportunity to further the science regarding work schedules and fatigue. Potential studies include examining fatigue of drivers working and driving for extended hours; fatigue levels of drivers who sleep less than 5 hours per 24-hour period; modeling the relationship between amount of sleep and off-duty time; examining how fatigue varies across the work day and work week; examining the impacts of driving breaks; and potentially modeling the aspects of driver schedules that are associated with greater fatigue.

APPENDIX A: LITERATURE REVIEW

The published literature was reviewed for recent information pertinent to the issue of CMV driver fatigue and recovery times needed between work weeks, with a focus on four areas:

1. New studies on the need for recovery from fatigue and the effectiveness of the 34-hour restart.
2. Significant findings from domestic and international research relating to commercial vehicle driver fatigue.
3. Significant findings from the military, Federal Aviation Administration, transit industry, and Federal Railroad Administration (regulations for training railroad engineers) on the effectiveness and measurable safety benefits of an adequate recovery period.
4. Health outcomes and sleep among CMV drivers.

STUDIES ON THE NEED FOR RECOVERY FROM FATIGUE AND THE EFFECTIVENESS OF THE 34-HOUR RESTART

Crash Risk, Breaks, and 34-hour Restart

In addition to addressing the number of hours that a CMV driver may drive and be on duty, the HOS regulations set the minimum amount of time that must be reserved for rest, which includes behaviors that promote recovery and the ability to work again. These behavioral requirements include time not working in the form of breaks during work, and time away from work to recover from acute and chronic work fatigue. Additional support for the benefits of breaks has recently been reported. Increases in crash risk for driving up to 11 hours have been found, but crash odds were incrementally reduced by one and two breaks in the latter half of a 10- to 11-hour drive in truckload (TL) and less-than-truckload (LTL) drivers.(66,67)

This work also revealed that drivers who had 34 hours or more off-duty (i.e., a 34-hour restart) immediately prior to a driving period had a nearly 43 percent increase in crash odds, which diminished on subsequent work days. The reasons for this risk elevation following the 34-hour restart are unknown, including whether they are associated with drowsy driving. One recent CMV naturalistic study found approximately 30 percent of all observed instances of drowsiness occurred within the first hour of the work shift, and observed instances of drowsiness were twice as likely to occur between 6 a.m. and 9 a.m., as compared to baseline or non-drowsy driving.(68) A database study of falling-asleep crashes (all vehicles) in North Carolina also found that they peaked in frequency between 6 a.m. and 9 a.m.(69) These are the hours of the day when sleepiness can be elevated from no sleep the night before,(70) from multiple days of sleep restriction,(71,72) and/or from sleep inertia.(73)

The range of possible contributors to CMV driver drowsiness serves to emphasize the importance in determining whether any of the following factors contribute to driver fatigue and crash risk immediately after a 34-hour restart:

- Time of day of the first drive after restart.
- Duration of restart recovery sleep.
- Quality of restart recovery sleep.
- Continuous time awake prior to restart first drive.
- Time of day of sleep during restart.
- Extent to which non-driving work occurred prior to the first drive post-restart. [(74)]
- Drivers' perceptions of stress following the 34-hour restart. [(75)]
- Perceived difficulty of the drive.
- Perceived degree of drive hazards.
- Driver characteristics that have been found to be associated with elevated crash risk (e. g., younger age, high blood pressure).
- Prior exposure of drivers to a Fatigue Management Program (FMP).

Although the current driver restart study does not have sufficient data to evaluate crash risk per se, data has been acquired on factors that may contribute to driver safety and fatigue after 34-hour restarts, relative to Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations (CFR). These measures include SCEs, which are relevant to crash risk,[(76)] as well as work time, drive time, sleep-wake timing on work days and restart days, fatigue, sleepiness, stress, driver-reported age, and a variety of self-reported health conditions. These data were acquired across a representative group of trucking operations.

Drivers' Sleep on Workdays Versus Sleep on Off-duty Days

An issue central to the 34-hour restart provision is the promotion of adequate recovery from CMV driver fatigue by providing the "circadian advantages of nighttime sleep,"[(77)] which is defined in the regulation as two consecutive sleep opportunities during biological and environmental nights (operationalized as 1 a.m. to 5 a.m.). Thus, the 34-hour restart provision was intended to provide drivers an opportunity to obtain two 8-hour rest periods to promote recovery from cumulative sleep deprivation (i.e., sleep debt).[(78)] In addition, over the past 10 years there have been a number of naturalistic studies in which CMV drivers wore wrist actigraph devices to objectively record their sleep periods (onset/offset times) and sleep duration per 24 hours. Table 44 displays the results of three of these naturalistic studies, including the 2014 field study of the 34-hour restart provision.[(79,80 ,81)]

These studies (and others) confirm that the amount of sleep per 24 hours obtained by CMV drivers on workdays is consistently less than the amount of sleep per 24 hours obtained on non-workdays (gray background on Table 44), suggesting that drivers accumulate a sleep debt and attempt to pay it off by sleeping longer during restarts and days off. This response is consistent with laboratory evidence of the fatiguing effects of restricting sleep to less than 7 hours of time in bed per day for 1 week[(82,83)] and evidence of a compensatory increase in sleep duration for 1 or more nights being essential to help recover performance and alertness deficits following 5 days of sleep restriction.[(84)] The mean differences in Table 44 between sleep per 24 hours on workdays and non-workdays range from 1.3 hours to 2.7 hours per day.[85,86] This large range may be explained by the fact that drivers studied in the 2014 HOS restart field study[87] slept 0.5–1.0 hours more per 24 hours during workdays than in earlier studies.[88,89] The 2014 HOS restart field study[90] reported differences in sleep time per day between restart conditions (1 versus 2-nights available for sleep from 1 a.m. to 5 a.m.), either for workdays (mean = 6.0 hours versus 6.2 hours, respectively) or for restart non-workdays (mean = 8.8 hours versus 8.9 hours, respectively).[91] This finding is partly explained by the interaction of sleep time with time of day. Most drivers reverted to at least some nighttime sleep during both types of restart, which is the only way to ensure sleep continuity can be maintained for a long period (e.g., 8 or more hours) to avoid a circadian-mediated termination of sleep. Although the sleep times appear relatively similar in that the 2-night restart group slept 2-nights with 8.9 hours of sleep, whereas the 1-night restart group slept only one period with 8.8 hours of sleep, the cumulative difference is nearly 3 hours of additional sleep per week.

Table 44. Naturalistic studies of U.S. CMV drivers' 24-hour sleep measured with wrist actigraphy.

Characteristics of study	Van Dongen & Mollicone[92]	Hanowski et al.[93]	Dinges et al.[94]
Number of drivers	106	29	12
Data recorded per driver	2 weeks	1-16 weeks	4 weeks
Conditions	Sleep on workdays after 1 restart break (1–5 a.m.) Sleep on workdays after ≥ 2 restart breaks (1–5 a.m.) Sleep during an off-duty restart period with 1 nocturnal period (1–5 a.m.) Sleep during an off-duty restart period with ≥ 2 nocturnal periods (1–5 a.m.)	24 h before critical incident in which truck judged to be at fault Overall sleep quantity (per 24-h period using midnight centered using the Cole-Kripke algorithm)	Sleep on workdays with no FMT* feedback Sleep on non-workdays following workdays with no FMT feedback Sleep on work days with FMT feedback Sleep on non-workdays following workdays with FMT feedback
Mean sleep time per 24 h (hours ± SD/SE)	(1) 6.0 ± 0.2 (SE) (2) 6.2 ± 0.1 (SE) (3) 8.8 ± 0.3 (SE) (4) 8.9 ± 0.2 (SE)	(1) 5.25 ± 2.15 (SD) (2) 6.70 ± 1.65 (SD)	(1) 5.23 (2) 6.53 (3) 5.02 (4) 7.52
Mean difference between conditions	1 vs. 2: 0.2 h (no p-value reported) 2 vs. 3: 0.1 h (no p-value reported)	1 vs. 2: 1.45 h (p = 0.0005)	1 vs. 2: 1.30 h (p = 0.018) 3 vs. 4: 2.50 h (p = 0.0004)

*Fatigue management technologies (FMTs) that provided alertness/drowsiness feedback to drivers

The results of Van Dongen and Mollicone[95] suggest that the 2-night, 34-hour restart may be essential for drivers to obtain increased recovery sleep per 24 hours, if the 1-night restart drivers do not revert back to sleeping at night during their restart. Thus, the 34-hour restart provision that included two nocturnal sleep periods provided greater recovery from the sleep debt of the prior duty period (i.e., 6.2 hours of sleep per day) than did the 34-hour restart with one nocturnal period, even though both restart schedules did not differ in actigraphy-measured total sleep per 24 hours. Finally, it is important to note that although actigraphy is a more accurate measure of sleep duration than self-reports of sleep duration,(96) like the latter, it tends to overestimate physiological sleep time.(97)

FINDINGS FROM DOMESTIC AND INTERNATIONAL RESEARCH RELATING TO COMMERCIAL VEHICLE DRIVER FATIGUE AND TECHNOLOGIES TO MANAGE FATIGUE

Human Factors and Ways to Reduce Fatigue-Related CMV Crashes

The Canadian Council of Motor Transport Administrators (CCMTA) completed a major report in 2011 entitled "Addressing Human Factors in the Motor Carrier Industry in Canada."(98) The report found that numerous sources and methodologies indicate the most significant causation factors for CMV crashes relate to drivers' recognition (caused either by fatigue [hypovigilance] or distraction) and decision errors, rather than performance errors or the use of drugs and alcohol. This resulted in a set of 44 action items to address fatigue, distraction, and risky driving. Although not mentioned in the CCMTA report, the relationships between fatigue, distraction, and risky behaviors are more intimate than commonly assumed. An extensive naturalistic study of SCEs found that the most frequent critical reasons assigned to CMV drivers for SCEs involved internal distractions (57.1 percent), external distractions (11.4 percent), and drowsiness (8.9 percent).(99) Recent scientific studies have established that sleep loss increases distractibility,(100) which suggests inadequate sleep can be central to driver inattention and distractibility.

The CCMTA report concluded that HOS regulations are necessary but not sufficient to address fatigue in the motor carrier industry.(101) Although HOS rules were regarded as the foundation of fatigue management, the report proposed various initiatives to generate a comprehensive and efficient fatigue management approach endorsed by industry and government. Among the initiatives the report recommended to reduce fatigue-related CMV crashes were the following:

- HOS rules enforced with tamper-proof equipment (e.g., electronic onboard recorders).
- Evaluation of the operational and safety effects of new HOS rules in Canada.
- Study of the psychological determinants of the decision to keep driving while fatigued.
- Study of pay structure as a determinant of the decision to keep driving while drowsy.
- Increased driver training in the causes, consequences, and management of fatigue.
- Adoption of Web-based FMPs by all stakeholders.
- Increased use of scientific evidence on the mitigation of fatigue by recovery sleep.
- Evaluation and implementation of fatigue monitoring technologies.
- Implementation of crash avoidance technologies (e.g., collision warning systems).
- Screening and treatment of obstructive sleep apnea (OSA) in CMV operators.
- Increase understanding of how to optimize rest areas for fatigue mitigation.

- Installation of lateral and central rumble strips.

Human Factors and Technologies to Reduce Fatigue-Related Risks in CMV Drivers

Inadequate sleep quantity and quality each day are the primary contributors to fatigue and loss of alertness in CMV drivers. Sleep quantity and quality are heavily influenced by sleep environment. Drivers have consistently been observed to sleep longer during restart and when off duty at home, than during work weeks (as shown in Table 44). On the other hand, sleep quality is rarely assessed, even though it is primarily a subjective rating. It is important to assess quality as well, because the reason sleep may be of shorter duration on workdays may relate to disruptions of sleep that reduce the quality, and thus the ability, to sleep. A recent study of Australian truck drivers found that sleep quality was rated as being higher at home than in the truck ($p < 0.05$). The main obstacles to obtaining good sleep at home were noise and family issues, and the main obstacles to obtaining good sleep when away from home were noise, temperature, and finding a suitable place to stop the truck.(102) The Australian study suggests the domain of technologies for monitoring and mitigating fatigue in CMV drivers should include the sleeping environment during on-duty and off-duty periods.

Since humans are genetically programmed to sleep each day during the nocturnal period, they cannot reverse this biological imperative without accumulating a sleep debt (as shown in Table 44) and suffering cumulative adverse health effects.(103) Maintaining human alertness and behavioral capability under conditions of sleep loss and circadian misalignment requires FMTs to be able to evaluate:

- Dynamic nonlinear modulation of performance capability by the interaction of sleep homeostatic drive and circadian regulation.
- Large differences among people in neurobehavioral vulnerability to sleep loss.
- Error in subjective estimates of fatigue on performance.
- Informing people of the need for recovery sleep.(104)

Therefore, the ability of those who work/drive at night to obtain adequate sleep during duty periods requires optimizing the sleep environment to minimize sleep debt, and optimizing the detection of driver fatigue from sleep debt when working and driving. It has increasingly been noted in recent years that the growing number of cost-effective FMTs can have a key role in minimizing sleep debt and maximizing driver alertness. (See References 105, 106, 107, and 108). Promising areas of technology for managing fatigue risk in safety-sensitive occupations, such as CMV driving, include preventing fatigue by optimizing work-rest schedules using biomathematical models of performance changes associated with sleep homeostatic and circadian dynamics; use of technologies such as the PVT-B as a quick aid for detecting fatigue from sleep loss;(109) and online video or machine-vision tracking of facial signs of sleepiness (e.g., percentage of eye closure [PERCLOS]), which have been validated to be associated with lapses of attention(110) and drowsy driving.(111) However, there have been few systematic evaluations of the extent to which FMTs can improve driver sleep and waking alertness. One notable exception is a naturalistic study in which a variety of FMT approaches were combined. This study revealed that during night driving, FMT feedback significantly reduced drivers' drowsiness ($p = 0.004$) and lane tracking variability ($p = 0.007$), and significantly increased driver sleep duration on days off duty by an average of 1 hour ($p = 0.018$).[(112)]

FINDINGS FROM THE MILITARY, FEDERAL AVIATION ADMINISTRATION, TRANSIT INDUSTRY, AND FEDERAL RAILROAD ADMINISTRATION (REGULATIONS FOR TRAINING RAILROAD ENGINEERS) ON THE EFFECTIVENESS AND MEASURABLE SAFETY BENEFITS OF AN ADEQUATE RECOVERY PERIOD

Fatigue Management in Commercial Aviation

Fatigue management was also a focus of an extensive review of aircrew fatigue, sleep need and circadian rhythmicity, and fatigue countermeasures.[(113)] The authors concluded that although aviation technology that allows travel over multiple time zones in a single day is a major advance, it poses substantial challenges to sleep and circadian physiology, which can result in flight crew fatigue. Their analysis had many parallels to the fatigue issues faced in commercial trucking. Operational demands resulting in extended work days, increased workload levels, reduced sleep opportunities, and disrupted circadian cycle continue to pose significant challenges during aviation operations. Current prescriptive approaches to fatigue prevention in commercial aviation do not adequately address sleep and circadian challenges associated with operations that run 24 hours per day, 7 days per week, nor do they provide operational flexibility. This has resulted in increasing interest in evidence-based nonprescriptive approaches for the management of fatigue in aviation operations. The authors conclude there is a need to develop approaches that exceed current fatigue management practices by implementation of scientifically valid and operationally feasible technologies that adjust, in real-time, to an individual's fatigue level and provide an intervention to help manage the fatigue in flight crew members. They assert that, although it may not be possible at this time to know which FMTs will be most useful and acceptable in commercial aviation, it is fairly certain that in order for valid technologies to be used, they must not violate the privacy rights of individuals. It is for this reason they conclude that FMTs in commercial aviation should first be developed as personal aids. They also conclude these technologies must be used responsibly, as they are not a substitute for reasonable working conditions. They anticipate that if these principles are followed, information from FMTs can help people involved in commercial aviation to be less fatigued and more alert, and this is an achievable goal worthy of our best efforts.

Sleep, Fatigue, and Accidents in the U.S. Railroad Industry

A recent Federal Railroad Administration report provided a comprehensive description of fatigue in U.S. railroad workers employed in safety-sensitive positions.[(114)] Five survey studies were conducted between 2006 and 2011 on maintenance-of-way employees, signalmen, dispatchers, train and engine (T&E) employees, and T&E employees engaged in passenger service. These studies were re-analyzed and compared with regard to work schedules and sleep patterns. Fatigue exposure was determined by analysis of work schedules and sleep patterns with a fatigue biomathematical model, the Fatigue Avoidance Scheduling Tool (FAST). Twelve different schedules of work were identified in the five groups of railroad employees. Work schedules largely determined sleep patterns, which, in turn, determined fatigue exposure. T&E crews and dispatchers had the highest fatigue exposure, but these two groups had considerably less fatigue exposure than T&E crews who were involved in accidents. Passenger service T&E employees had the least fatigue exposure, even though the distribution of work time was highly similar to that of T&E employees. This difference in fatigue exposure may be due to the greater predictability of work for the passenger service T&E. The authors found the risk (probability × cost) of an accident caused by human factors increased exponentially with fatigue exposure. The methodology they applied makes it possible to identify differences in sleep patterns as a function of work group and work schedule. They recommend that future work on fatigue in occupational groups should focus on similar methods to expand knowledge of the role of work schedules on sleep, fatigue, and accident risk.

HEALTH OUTCOMES AND SLEEP AMONG CMV DRIVERS

Obesity is a major public health and economic concern due to its promotion of morbidity and mortality. Obesity-related conditions include OSA, heart disease, stroke, type 2 diabetes, and certain types of cancer—some of the leading causes of preventable death. Currently, 34.9 percent (78.6 million) of U.S. adults are obese.[(115)] A recent Centers for Disease Control and Prevention (CDC) obesity prevalence study by occupation of 37,626 employed Washington State respondents found that truck drivers had the highest prevalence of obesity (38.6 percent) among 28 occupations.[(116)]

A new study utilized 88,246 commercial driver medical examinations from 2004–13 to estimate the prevalence of obesity, comorbidities, and certification outcomes.[(117)] A majority of the drivers were obese (53.3 percent, BMI > 30.0 kg/m^2), and many were morbidly obese (26.6 percent, BMI > 35.0 kg/m^2), which was found to be higher than prior reports. Obese drivers were less likely to be certified for 2 years and more likely to report heart disease, hypertension, diabetes mellitus, nervous disorders, sleep disorders, and chronic low back pain (all $p < 0.0001$). There were relationships between multiple potentially disqualifying conditions and increasing obesity ($p < 0.0001$). Morbid obesity prevalence increased 8.9 percent and prevalence of three or more conditions increased fourfold between 2005 and 2012. The authors concluded that obesity is related to multiple medical factors as well as increasing numbers of conditions that limit driving certification.[(118)]

These recent studies indicating a high prevalence of obesity and associated health risks in CMV drivers have implications for driver fatigue and alertness. It has been well established that obesity is the cause of OSA in the vast majority of adults, and that if left untreated or under-treated, sleep apnea leads to excessive daytime sleepiness in CMV drivers,[(119)] which has been associated with crash risk.[(120)] Obesity also has been associated with driver fatigue and SCEs.[(121,122)] There is also epidemiological evidence that restriction of daily sleep time to less than 6 hours per day results in an increased prevalence risk of obesity, as well as diabetes, hypertension, cardiovascular disease, and all-cause mortality. This raises the possibility that a combination of reduced sleep time during duty periods (as shown in Table 44) and a limited selection of healthy food availability while on the road[(123)] may promote obesity in drivers, which in turn places them at greater risk for disorders that further limit their ability to cope with sleep debt and operate safely.

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APPENDIX B: BACKGROUND SURVEY

Please answer all questions as accurately as possible.
All information is confidential and anonymous.

Boxes should get a checkmark or an "X". Example: X

Blank lines allow you to input your answer as a number or text response.

1. **Age?** _____years
2. **Gender?**
   __ male
   __ female
3. **Married?**
   __ no
   __ yes
4. **What is you height?**
   ___ feet
   ___ inches
5. **What is your weight?** ______ pounds
6. **Years of driving experience** ______ years
7. **Years at present company** _______ years
8. **Type of driver?** Day / Night/ Mixed
9. **What is your home terminal time zone used for HOS logs** _______ (Eastern/Central Mountain/Pacific)
10. **Have you participated in a Fatigue Management Program (FMP)?**
    __ no
    __ yes
    __ unsure
11. **Has a physician informed you that you have any of the following conditions? (Mark all that apply to you.)**
    __ Sleep apnea
    __ Diabetes
    __ High blood pressure
    __ Insomnia
12. **Do you use any of the following? (Mark all that apply to you)**
    __ CPAP for sleep apnea
    __ Medication for diabetes
    __ Medication for high blood pressure
    __ Medication for insomnia

13. How often do you experience pain of any kind during a typical daily work shift? (Check only 1 box)

__ 0-5% of shift

__ 5-25% of shift

__ 25-50% of shift

__ 50-75% of shift

__ 75% or more of shift

14. Do you typically consume caffeine? If yes, indicate the average amount consumed below.

__ No

__ Yes (If yes, for all categories that apply, indicate amount consumed in a typical day.)

Coffees	_______ cups per day
Cola drinks	_______ drinks per day
Energy drinks	_______ drinks per day
Caffeine pills	_______ pills per day
Caffeine gum	_______ sticks/pieces per day
Tea (not herbal)	_______ cups per day

15. Do you typically use tobacco products? If yes, indicate the average amount used below (Check all that apply to a typical daily work shift.)

__ No

__ Yes (If yes, for all categories that apply, indicate amount used in a typical day.)

Cigarettes	_______ cigarettes per day
Cigars	_______ cigars per day
Chew tobacco	_______ pinches/pouches per day
Smoke pipe	_______ bowls per day
Nicotine gum	_______ sticks/pieces per day

APPENDIX C—INFORMED CONSENT FORM AND VTTI IRB APPROVAL LETTER

Informed Consent for Participants in Research Projects Involving Human Participants

Title of Project: Commercial Motor Vehicle (CMV) Driver Restart Study

Investigators: Daniel Mollicone – Pulsar Informatics, Inc.
Richard Hanowski – Virginia Tech Transportation Institute

I. Purpose of this Research/Project

This study will look at the effectiveness of the 34-hour restart rule, as described in the Hours-of-Service (HOS) Regulations. This will help us better understand driver behavior and driving patterns. Data from this study will be used in a confidential way to understand commercial vehicle driving. This Informed Consent Form is to explain your role in this study.

II. Procedures

If you agree to participate in this study, you will be asked to do the following:

1. Read and sign this Informed Consent Form.
2. Fill out a W9 form.
3. Complete a Heath Assessment Questionnaire (on the Smartphone provided to you for this study) at the beginning of your participation time.
4. Allow a researcher to take a digital photo of your face – this will be used to identify you as the correct participant when looking at the video data.
5. Drive an instrumented vehicle for up to 5 months on your normal route(s). The vehicle instrumentation includes a camera that records your face and upper body in the driver's seat and a second camera facing out the front of the truck at the forward road. Video is recorded in 12-second snippets (8 seconds before, 4 seconds after) surrounding an event of interest such as hard braking or acceleration, hard lateral swerves, and speeding (10 mph over the posted speed limit). The corresponding vehicle data is also collected at the same time (how hard you brake, your speed, GPS location, etc.).
6. Wear an actigraph watch for up to 5 months. This watch is to be worn at all times (unless swimming) and will monitor your sleeping patterns. You will be required to charge the watch battery once per week in order to keep it running.
7. Complete the following assessments three times a day, on both working days and non-working days. On working days, you will complete each assessment prior to the start of your first driving period, approximately halfway through the total driving period for your day, and at the end of your driving period. On non-working days, you will complete each assessment within 2 hours of waking, approximately halfway through your day, and within 2 hours of going to bed. During each of the described time periods, you will complete:
    a. A psychomotor vigilance test (PVT) that requires you to look at the Smartphone screen and tap the screen when you see a counter appear at random (chance) intervals during the 3-minute test. This test measures your reaction time.

b. A drowsiness assessment, caffeine diary, stress rating, and a sleep/wake/duty diary on the provided Smartphone.

These assessments will take approximately 30 minutes each day. You will also be required to charge the Smartphone approximately once per day in order to keep it running.

8. Log your hours of service in the BigRoad app on the Smartphone and allow a DashLink adapter to be plugged into your vehicle diagnostic port. You will be required to log your hours of service in the BigRoad app throughout the study period, in addition to logging your hours of service using your company procedures to be compliant with law enforcement.
9. Participate in a brief (approximately 5 – 10 minute) phone call with a researcher, approximately once a week, to review your assessments.
10. Participate in a debriefing phone call at the end of your participation to provide feedback from the study to a member of the research team. You will also receive instructions on how to return the equipment at this time.

For this study we will be collecting data from up to 300 commercial-vehicle drivers like you. The starting day of data collection is determined by the date when you start driving an instrumented vehicle.

III. Risks and Discomforts

There are some risks and discomforts to which you may be exposed to in volunteering for this research. These risks include:

1. The risk of a crash associated with driving a commercial vehicle as you usually do.
2. The risk of completing the questionnaires is minimal and similar to completing office paperwork.
3. If you do not already have a Lytx Video Event Recorder (VER) in your vehicle, there may be stress associated with being recorded while driving if the VER is triggered, for example, due to hard braking, hard acceleration, hard lateral swerve, or speeding. The video will show your face, and a forward view and your actions in response to the driving situation.
4. If you drive into an area where cameras are not allowed, including international border crossings, certain military and intelligence locations, and certain manufacturing facilities, there is a risk that you may be detained or arrested or that your vehicle may be impounded.
5. There is an additional risk not encountered in everyday driving. While you are driving the instrumented vehicle, the VER, if triggered by an event, will record video of you, your actions, and surrounding traffic. In the event of an accident, there is a risk that the video and vehicle parametric data could be obtained in conjunction with a government inquiry or in litigation or dispute resolution. Even if you are not in any accidents, there is a risk of someone outside of the study requesting your data. However, under normal circumstances your identity and the company you work for will be kept confidential.
6. The risk that if the provided Smartphone is lost or stolen, or confiscated by law enforcement or your employer, that these other persons will be able to view your research data and learn your participant number.
7. The risk that your study data may be viewed by people outside of the research team if the Smartphone or actigraph watch is lost in the mail during the return process. However, if

either is lost in the mail, there is nothing that ties the data on the Smartphone or actigraph watch to you personally that will be available to whoever finds it.

The following precautions will be taken to ensure minimal risk to the participants:

1. You will be instructed to follow your company's safety policies.
2. The Smartphone apps you will use during the study will not operate while the vehicle is moving.
3. Your participation in (or withdrawal from) this study does not have any influence on your status as an employee with your current company.
4. All data collection equipment will be mounted such that, to the greatest extent possible, it will not pose a hazard in any foreseeable way.
5. If your provided Smartphone is lost or stolen, we will perform a remote data wipe.
6. In order to help protect the anonymity of your data, it is advised not to include your name and/or mailing address in any way on, or in, the packaging when returning the equipment at the end of the study. The research team will be tracking which piece of equipment belongs to each driver so there is no need to provide your name with the mailing.

IV. Benefits

There are no direct benefits to you for the data collection portion of this study, other than you will have the opportunity to be involved in this very important research study. The results of this study will be briefed to Congress and will be used to modify, as needed, the current CMV HOS regulations.

V. Extent of Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participating, your name and the company you work for will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (e.g., Participant 001, Location A). It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

While you are driving the vehicle, a camera will record 12-second snippets (8 seconds before, 4 seconds after) if the VER is triggered because of an event of interest such as hard braking, hard acceleration, hard lateral swerve, or speeding (10 mph over the posted speed limit). Video of your face and out the front of your truck will be recorded during this 12 seconds, as well as audio. An example is shown below.

All Lytx data will be encrypted at the time of data collection and will be decrypted only once it arrives back at Lytx and will be stored on a secure server. Access to the video and audio will be limited to Lytx personnel only.

If you are involved in a crash while participating in this study, the data collection equipment in your vehicle will likely capture the events leading up to the event. You are under NO LEGAL OBLIGATION to voluntarily mention the data collection equipment or your participation in this study at the time of a crash or traffic offense.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution. You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

Each video file will be coded for driver behavior and environmental and roadway conditions. The video data will be archived 90 days from the day it is transferred to Lytx and deleted at the end of the study. The coded data set (with no information that could be used to identify you) will be posted online at the end of the study for public use.

VI. Compensation

You may receive up to $2,166 if you participate for the full 5 months of this study, and if you complete all assessments as requested. You will receive three payments over the course of your participation as follows:

- You will receive $75 at the initial sign up meeting for signing the ICF and completing the health assessment. This will be paid to you in cash or by check at the time of the meeting if possible, or a check will be mailed to your home within one week.
    - $50 for attending the initial briefing and sign up of the study
    - $25 for completing a health assessment questionnaire during the initial briefing

- You will receive a second payment of up to $1,891 for your participation in the study if you complete all 5 months. You will receive this payment by check mailed to your home within 30 days of completing your participation.

   - Up to $1,606 for 22 weeks of participation. You will be asked to complete three Smartphone assessments, three times per day and may receive the following payment:
     - $3 per assessment × 3 assessments/day = up to $9/day
     - $9/day × 7 days in a week + $10 bonus for completing all assessments in a week = up to $73/week
     - 22 weeks × $73/week = $1,606 for completing all assessments
   - $25 for participating in a debriefing phone call at the end of the study
   - $260 bonus for completing all 5 months of participation

- You will receive a third, and final, payment of up to $200 if you return all three pieces of equipment. Pre-paid packaging materials will be sent to you at the end of the study for you to use to return the actigraph watch, Smartphone, and Lytx system. You will receive this payment by check mailed to your home within 30 days of receiving back the equipment.
   - $50 for returning the actigraph watch
   - $50 for returning the Smartphone
   - $100 for returning the Lytx system

If you elect to withdraw from the study or if your employment is terminated, you will be compensated for your participation up to that time. You will be asked to return the actigraph watch and Smartphone if you end your participation early.

VII. Freedom to Withdraw

Participation in this research is voluntary. You are free to withdraw at any time without penalty. If you withdraw, are dismissed from the study, or if your employment is terminated, we will retain data collected before that time, but delete any data collected in the interval between when we become aware of the withdrawal/dismissal and before we are able to remove the data collection equipment. If you withdraw from the study, or if your employment is terminated, you will be paid for your participation up to that time. Withdrawal from this study will not adversely affect your employment status.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Participants at Virginia Polytechnic Institute and State University. You should know that this approval has been obtained and is valid for the dates listed at the bottom of this form.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. You will be instructed to follow your company’s safety policies.
2. You will maintain a valid CDL-A throughout the course of the study.
3. To follow the experimental procedures as well as I can.
4. To inform the experimenters if I incur difficulties of any type.

X. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty.

______________________	______________________	______________
Participant's name (print)	*Signature*	Date
______________________	______________________	______________
Experimenter's name (print)	*Signature*	Date

Should I have any questions about this research or its conduct, I may contact:

Daniel Mollicone, *Co-Investigator*	(206) 673-4733, daniel@pulsarinformatics.com
Richard Hanowski, *Principal Investigator*	(540) 231-1513, rhanowski@vtti.vt.edu

If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore, Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects
Telephone: (540) 231-4991; Email: moored@vt.edu

Participants must be given a complete signed copy (or duplicate original) of the Informed Consent.

VTTI IRB APPROVAL LETTER

VirginiaTech

Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE:	February 18, 2015
TO:	Richard J Hanowski, Jeff Hickman, Rebecca Hammond, Devon D Moeller, Mark E Golusky, Matthew Clayton Camden, Susan Soccolich, Feng Guo, Daniel Mollicone, Yuen Kwan Lo, et. al.
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE:	CMV Driver Restart
IRB NUMBER:	**15-063**

Effective February 18, 2015, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 4,5,6,7**
Protocol Approval Date:	**February 18, 2015**
Protocol Expiration Date:	**February 17, 2016**
Continuing Review Due Date*:	**February 3, 2016**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
02/17/2015	15147501	Federal Motor Carrier Safety Administration	Compared on 02/18/2015

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.

APPENDIX D—RECRUITMENT POSTER

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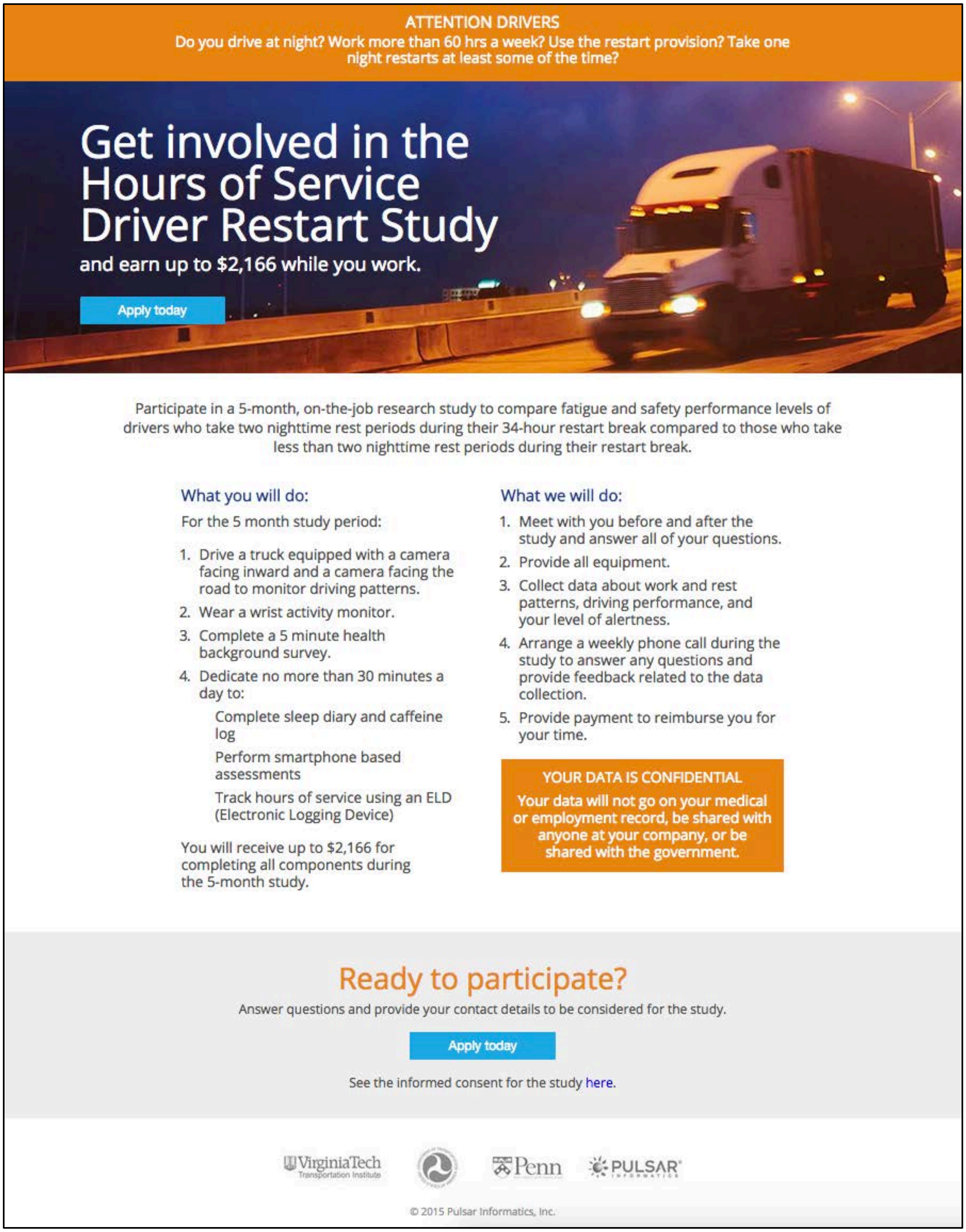
APPENDIX E—SCREENSHOTS OF RESTARTSTUDY.COM RECRUITMENT WEBSITE



ATTENTION DRIVERS
Do you drive at night? Work more than 60 hrs a week? Use the restart provision? Take one night restarts at least some of the time?

Get involved in the Hours of Service Driver Restart Study

and earn up to $2,166 while you work.

Apply today

Participate in a 5-month, on-the-job research study to compare fatigue and safety performance levels of drivers who take two nighttime rest periods during their 34-hour restart break compared to those who take less than two nighttime rest periods during their restart break.

What you will do:

For the 5 month study period:

1. Drive a truck equipped with a camera facing inward and a camera facing the road to monitor driving patterns.
2. Wear a wrist activity monitor.
3. Complete a 5 minute health background survey.
4. Dedicate no more than 30 minutes a day to:
   - Complete sleep diary and caffeine log
   - Perform smartphone based assessments
   - Track hours of service using an ELD (Electronic Logging Device)

You will receive up to $2,166 for completing all components during the 5-month study.

What we will do:

1. Meet with you before and after the study and answer all of your questions.
2. Provide all equipment.
3. Collect data about work and rest patterns, driving performance, and your level of alertness.
4. Arrange a weekly phone call during the study to answer any questions and provide feedback related to the data collection.
5. Provide payment to reimburse you for your time.

YOUR DATA IS CONFIDENTIAL
Your data will not go on your medical or employment record, be shared with anyone at your company, or be shared with the government.

Ready to participate?

Answer questions and provide your contact details to be considered for the study.

Apply today

See the informed consent for the study here.

VirginiaTech Transportation Institute Penn PULSAR

CMV Driver Restart – Recruitment Questionnaire

Your Information

First name

Last name

Home zip code

Email

Cell phone

Employer's name

DOT Number*(on the door of your vehicle)*

Supervisor's name*(your name if independent owner operator)*

Supervisor's contact number*(your number if independent owner operator)*

Questions

How many power units are at your employer?

Not selected

What type of vehicle do you drive?

Not selected

What geographic area do you regularly operate in?

Not selected

How many miles do you normally drive each week?

Not selected

How many miles did you drive in 2014 (January thru December)?

Which 395.3(b) weekly hour of service rule do you operate under?

Not selected

How often does any part of your driving occur at night (between 1am and 5am)?

Not selected

How many on-duty and driving hours do you normally log in a seven day period?

Not selected

How often do you use the restart provision?

Not selected

How often do you take restarts more than once every 168 hours (7 days)?

Not selected

How many nights are typically included on your restarts?

Not selected

Do you have Drivecam or SmartDrive installed in your truck?

Not selected

Submit

VirginiaTech Transportation Institute   Penn   PULSAR INFORMATICS

APPENDIX F—FMCSA INDEPENDENT REVIEW PANEL

In the regular course of business, FMCSA utilizes an independent peer review when conducting research activities. At the project's outset, the panel evaluates the clarity of the research questions, the validity of the research methodology, and the quality of the data collection plan. The peer review panel also evaluates the draft final report and comments on the strength of the analyses and the appropriateness of the study conclusions. The Consolidated and Further Continuing Appropriations Act, 2015, required that the initial CMV Driver Restart Study work plan and final report be subject to an independent peer review. The USDOT OIG reviewed the selection of the independent review panel and concluded that "FMCSA selected individuals with relevant medical and scientific expertise." The peer review panel team members communicated their project reviews and inquiries directly with FMCSA staff.

SELECTION PROCESS AND CRITERIA

FMCSA selected the members of the independent peer review panel based on their scientific and medical expertise. To identify a broad pool of potential team members, FMCSA reached out to the National Academy of Sciences Committee on National Statistics, the American Statistical Association, and several Federal research agencies, such as NIH, for advice on independent experts who could serve on the panel. FMCSA met to review the candidates and narrowed the list to four experts. These individuals represent expertise in statistics, human subject research design, and medical research. FMCSA also gave due consideration to each individual's independence and ability to objectively review the study, based on a review of their publicly available biographical materials, academic vitae, and résumés. Two of the members are Federal scientists who are required to abide by government-wide ethics and conflict of interest rules. As Federal employees, they do not have ties to industry or other outside groups which could impair their ability to make objective professional judgments regarding the study plan. Two other peer review team members hold academic positions and have experience with national scientific study panels and grant-funded research. A review of their professional backgrounds does not indicate any financial or other ties to industry or other outside groups which could impair their ability to review the study plan and findings objectively. Each of the four peer review panel members came highly recommended by professional colleagues. Each member was required to sign a nondisclosure/conflict of interest statement.

In selecting the peer review panel members, FMCSA followed the overall guidance issued by the OMB *Final Information Quality Bulletin for Peer Review* (issued December 16, 2004).[(124)] FMCSA also followed the policies employed by the National Academy of Sciences to ensure independence and avoidance of conflicts of interest. For further information on this topic, see National Academy of Sciences, *Policy and Procedures on Committee Composition and Balance and Conflicts of Interest for Committees Used in the Development of Reports*, May 2003.[(125)] The National Academy of Sciences defines conflict of interest as "any financial or other interest that conflicts with the service of an individual on the review panel because it could impair the individual's objectivity or could create an unfair competitive advantage of a person or organization."[(125)]

ROLES AND RESPONSIBILITIES

FMCSA provided the peer review team with the project's draft work plan and methodological design for their review and comment. The team members attended the project kick-off meeting in February 2015 and provided comments to FMCSA. FMCSA evaluated the comments and modified the draft work plan as necessary. Once data collection began, the peer review team was informed of any significant issues that could have changed the research design. FMCSA provided the peer review team with copies of the draft final report for their review and comment.

The Peer Review Charge for this study provided the specific activities assigned to the peer review panel. As recommended by OMB guidelines, FMCSA engaged the peer review team early in the research study process to benefit from their expert review of the research design and methodology.

The peer review panel's evaluation of the initial study plan included a review of the study hypothesis, soundness of the research methodology, adequacy of the technology used to measure safety performance and driver fatigue, data collection protocol, and analysis plan. The peer review panel also commented on the study's performance measures to properly evaluate the study outcomes. The independent review of the final report included an evaluation of whether the findings in the report were supportable in view of the statistical evidence provided and whether the report addressed all the items in the initial study plan (see Appendix G and Appendix H).

KEY MILESTONES FOR THE INDEPENDENT PEER REVIEW PANEL

- Peer review panel established – January 2015.
- Peer review panel information submitted to OIG – February 2015.
- Project kick-off – February 2015.
- Peer review panel reviewed study plan prior to submission to OIG – February 2015.
- Peer review panel reviewed draft final report prior to submission to OIG – November 2015.

APPENDIX G—PEER REVIEW REPORT SUMMARY: STUDY WORK PLAN AND METHODOLOGY

COMMERCIAL MOTOR VEHICLE (CMV) DRIVER RESTART STUDY: PEER REVIEW OF DRAFT DETAILED WORK PLAN

The present naturalistic study is designed to compare the effects of two commercial motor vehicle (CMV) driver work schedules (restart periods that include 1 versus 2 or more nights) on safety-critical events (SCEs), operator fatigue, and health. The study design is generally solid and reflects the intent of the Congressional directive made through the 2015 Consolidated and Further Continuing Appropriations Act.

PROJECT STRENGTHS:

1. The peer review panel is unanimous in congratulating the FMCSA on its selection of an outstanding research team, which consists of world-renowned experts in fatigue research, naturalistic driving studies, complex field research, and statistics.
2. The use of a mixed "within- and between-subject" design is appropriate and will serve to maximize statistical power.
3. The advanced technology used to capture safety events, sleep, fatigue, and other important variables, coupled with the planned intense follow-up, is likely to result in very high quality data.
4. Although lowering the threshold of the OBMS system to capture potential SCEs is not a perfect solution, it is creative and currently the best way to help ensure that an adequate number of SCEs are captured in a "control/comparison" condition.

PROJECT WEAKNESSES:

1. Given that the primary intent of the study is to examine safety and fatigue in 1-night versus 2-night restarts, sampling to include fleets of all sizes (i.e., small, medium, and large) and operations (including long-haul, regional, and short-haul) in various sectors of the industry for the sake of "generalizability" potentially detracts from the study. The peer review panel recognizes that the researchers' mandate is to study a "representative" sample. However, from a scientific standpoint, the purpose of ensuring representativeness of a study sample is typically to facilitate the subsequent generalizability of the findings. However, successful generalization requires and pre-supposes (a) that the cells in the sampling plan represent meaningful populations—i.e., populations that might reasonably be expected to be differentially affected by independent variable(s) (in this case, the 1- versus 2-night restart conditions) and (b) that each cell in the sampling plan will have an "n" sufficient to warrant generalization of the study findings. The peer review panel feels that neither of these conditions are satisfied (i.e., that the mandated 36-cell sampling plan is ill-conceived) and worries that expending resources (time and effort) trying to ensure that each of

these cells has representation could potentially (and needlessly) impede study efficiency and progress.

2. The original study design did not sufficiently account for driver self-selection effects for choosing a restart condition as well as other potential confounding variables. [This was discussed during the conference call and the investigators indicated that they understood the issues and were making changes to address this weakness. See recommendations below.]
3. It is not clear what will be done during the recruitment phase for a driver who qualifies with respect to the eligibility driving criteria set out on page 14 [of the draft study work plan] (Recruitment and Retention Plan) but who has, for example, a serious health problem. This is an ethical issue, as well as one that bears on the need to be clear about what is meant by generalizability.
4. As indicated previously, the use of smartphone technology to measure subjective fatigue and objective measures of performance is a significant strength. The importance that these devices not be used while driving is clearly understood and adequately addressed. However, it is not clear how the safeguards will impact data collection activities when deployed in team driving situations (i.e., if the device "lockout" while moving will prevent a team driver from entering data while off duty and prior to sleep or awakening in the sleeper berth). To the extent that the study sample includes such driving teams, these issues should be addressed.

Recommendations

Given the constraints imposed by the congressionally-directed research mandate, the proposed research plan is generally well-conceived, with appropriately selected dependent variables, appropriate methodology, and a reasonable plan for statistical analyses. Accordingly, although the peer review panel has several suggestions for the research team to consider, we offer only two actual recommendations:

1. There are many unknown confounds that may influence selection of a 1- versus 2-day restart. An effort should be made, for example, using propensity score matching, to balance the two conditions. This requires that more information be collected regarding the reasons for implementing one or the other restart condition. One possibility is to add a survey, perhaps as a smartphone app, that specifies the reason for the type of restart, and the possible reason for using the restart at all. The latter may be particularly helpful for characterizing drivers who take fewer restarts. An additional possibility is to add a question(s) to the background survey regarding the drivers' attitude[s] toward 1-night restarts in their own schedules.
2. Although generalizability is an important consideration, the current scheme for recruiting drivers does not facilitate the ability to make inferences regarding a more general population. A clear statement of who the target population is and the extent to which the study (recruited) population is representative of that target population should be added.

Suggestions:

The following are provided only as suggestions for the research team to consider as they conduct the study, analyses, and interpret the findings from this very important study. Accordingly, the research team should feel free to adopt or reject the following suggestions (which are in no particular order) as they see fit:

C. The current subjective measures of fatigue (KSS, FS) do not address the multidimensional nature of fatigue states, such as decreased task engagement, motivation, and the potential relationship between fatigue and broad personality traits such as extroversion and neuroticism. Some research on mood suggests that energetic arousal (or positive affect) is strongly correlated with extroversion and implies that introverts may be particularly prone to fatigue. Viewing fatigue as a complex of unpleasant state symptoms, high neurotic individuals might be more fatigue-prone, given their general tendency towards stress symptoms. This is arguably beyond the scope and intent of the study, but it may be that including broader measures to capture the multidimensional nature of driving-induced fatigue could prove informative, especially if the occurrence of SCEs is low.

D. Broaden the measures of fatigue and stress to capture the multidimensionality of stress and fatigue states. Consider including trait measures of fatigue.

E. Caffeine intake is being measured but not herbal or illicit stimulant use. If anonymity assurances will ensure accurate reporting, it might be beneficial to collect this information, as well.

F. As a follow-on to the first recommendation re: propensity score matching, it should be noted that new work has been developed for adaptive treatment studies in randomized trials called SMART designs by Susan Murphy (who just won a MacArthur Award for this work). If each restart period is thought of as an “adaptive treatment assignment” where the “assignment” depends on the driver’s previous “restart-experiences,” appropriate modifications of methods for the analysis of SMART-designed studies may be a useful approach for analysis of this naturalistic study.

G. Potentially meaningful characteristics of the trucking companies, for example, whether or not they have a fatigue management program (and the quality/comprehensiveness of those programs) is important, and worth capturing.

H. Given that this study is going to occur during the summer months, a statement regarding the possibility that time-of-year effects could affect the generalizability of the results might be considered (if the researchers agree that this is a possibility).

I. Anticipating that recruitment may not go according to schedule, the panel suggests that a protocol be specified ahead of time that outlines the steps that would be taken to increase driver recruitment. Having such a plan would add to the transparency of the study, its scientific rigor, and the ability to generalize results.

J. As part of the recruitment process, consider collecting information from carriers that quantify the prevalence of drivers in each recruitment category. This information could be used to improve the generalization of the study results to the population of interest, as defined in accordance with recommendation 2.

K. The researchers might consider augmenting the proposed initial data analyses with a few more exploratory data analyses that as a whole address the impact of self-selecting restart type and other cycle attributes that may confound the effect of the type of restart. For example, the proposed simple analysis might be repeated within groups defined by the reason for selecting the type of restart. Similar simple analyses that incorporate the number of days in each restart/duty cycle and attributes of the previous cycle(s) could potentially differentiate the type of restart from other potential causes of different rates of SCEs such as accumulated fatigue.

L. Similar to suggestions F and K, complex models developed for the final statistical analysis plan should focus on eliminating confounding due to competing potential causes of different rates of SCEs and other stress and fatigue outcomes.

SUMMARY AND COMMENT

The research team has produced a coherent and comprehensive research study plan that addresses critical questions regarding possible differential effects of restart schedules that include one versus two nighttime periods (during which nighttime sleep is typically obtained). The study is exceptionally well-designed given the constraints imposed by the congressionally-directed sampling requirements, which, in the unanimous opinion of the peer review panel, are inconsistent with the stated goal of facilitating the study's generalizability. Accordingly, the panel has produced only two recommendations: (a) application of 'propensity score matching' to account for self-selection effects that may be attributable to the various reasons for a 1- versus 2-night restart; and (b) a clear explication of the population to which the anticipated results will be generalized. In addition, a number of suggestions for possible modifications or additions to the design and/or analyses were provided by the panel—to be implemented (or not) at the discretion of this exceptional research team.

APPENDIX H—PEER REVIEW REPORT SUMMARY: FINAL REPORT

DATE: 25 NOVEMBER 2015

PROJECT SCOPE

The study mandate was to employ a naturalistic field study design to assess the relative effects of the 1- versus 2-night restart options in provision 395.3(c) on operational, performance, safety, health, and fatigue in commercial motor vehicle (CMV) drivers.

Peer Review Methodology

The review process implemented for this study—which included teleconferences with key study team members and the peer review panel members at critical junctures in the planning and execution phases of the study—were informative and productive (largely the result of the forethought and care with which these meetings were timed and prepared for by all involved, and the study team's willingness and ability to rapidly "adjust fire" as necessary). Accordingly, the draft final report contains few surprises, and as detailed below, we (the peer review panel) have only a few remaining questions and suggestions.

Clarity of Hypothesis

The study hypotheses were simple and clear: that the effects of the two restart provisions described in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, would differ significantly on outcomes reflecting operational performance, safety, health, and fatigue in commercial motor vehicle (CMV) drivers, with no a-priori hypotheses regarding *which* restart condition would prove more beneficial. The study team operationally defined each of the outcomes using appropriate and sensitive tests and measures, thus "putting flesh on" what were initially broad and nebulous conceptual requirements.

Validity of Research Design

This was a naturalistic field study, subject to all of the limitations inherent to such designs—in particular, the lack of experimental control (e.g., random assignment to 1- versus 2-night restart conditions) that unavoidably limits the ability to determine cause-effect relationships (as pointed out in the report itself, on page 75).

Another criticism of the research design was that, in a well-meaning effort to ensure representativeness of the study sample, there were many irrelevant but mandated "industry segments" (i.e., inclusion of driver categories that were unlikely to systematically impact any of the outcome variables, e.g., drivers of refrigerated trucks, flatbed trucks, panel trucks, etc.). Had the mandated list of driver categories been restricted to those potentially more relevant (e.g., long- versus short-haul) the ability of the study team to recruit for and detect the effects of these potentially more relevant/meaningful industry segments would have been enhanced.

Quality of Data Collection Activities

The peer review panel is unanimous in its praise of the study team, who in the draft final report dated November 2015, provide the major findings from a large, complex field study to assess the effects of the restart provisions in Sections 395.3(c) and 395.3(d) of Title 49, Code of Federal Regulations, on the operational, safety, health, and fatigue in commercial motor vehicle (CMV) drivers. By virtue of its scope and size, its nearly flawless execution (no significant protocol deviations), and the alacrity with which the data were analyzed and reported, this study sets a new mark for excellence in naturalistic field studies—a testament to the competence and dedication of the study team.

PEER REVIEW FINDINGS

Robustness and Depth of Analysis Method Used

The present data set is massive and the current analyses have only begun to "scratch the surface" of possibilities. It is anticipated that once the data set is made available to the broader research community, it will generate considerable excitement and further, in-depth analyses/exploration.

The study team has adequately conducted all of the required statistical analyses, and ha[s] been receptive to including further analyses requested by the peer review panel. As detailed in the comments by two members of the peer review panel, it was, within the past 2 weeks, suggested that the study team focus the analyses more sharply on the potential bias effects resulting from the differing levels of control that participating drivers exerted over the decision to restart after 1 or 2 nights. (Although this factor was included as a covariate in analyses, more concerted analyses to determine the impact of this factor on the various outcome variables was suggested—a suggestion readily accepted by the study team.) The study team subsequently provided details that satisfied the main concerns of the peer review panel, although presentation of additional analyses to strengthen the conclusions and offset potential selection bias-related criticisms are suggested. As an example, a panel member suggested that the study team might "repeat the presented analyses for subsets related to the probability the particular restart type was experienced" (see below), although several other valid approaches are possible.

Appropriateness of Methods for the Hypothesis Being Tested

Within the constraints inherent to naturalistic field studies, the methods were appropriate. The peer review panel was favorably impressed by the study team's utilization of cutting-edge technology, which helped ensure the currency, accuracy and validity of the data collected over the course of the study.

Extent to which the Conclusions Follow the Analysis

In general, and befitting a naturalistic (correlational) field study such as this, the draft final report contains few definitive conclusions regarding the relative benefits of the 1- versus 2-day (or more-than-2 days) restart options on the various outcome measures. Rather, the results of the analyses are mostly "allowed to speak for themselves."

Strengths and Limitations of Overall Product

The strengths of the product are considerable, and are generally derived from the obvious care/attention to detail with which the data were collected, and the clarity with which the initial results have been presented in the report.

The limitation of the product generally derive[d] from:

a) The limited ability to infer cause-effect relationships from naturalistic observational studies.

b) The short period of performance afforded to the study team (given another few months, it is likely that the study team would have conducted more extensive exploration and analyses of the data which would have enhanced the richness of the findings included in the report).

c) The mandated inclusion of a large number industry segments – not for scientifically valid or logical reasons (i.e., not because it was expected that these segments would actually account for significant amounts of variance) but to help ensure "representativeness." This non-scientific requirement unnecessarily added significant logistical (i.e., recruitment-related) burden to the study effort.

d) As detailed in the individual comments of some of the reviewers, it was felt that the organization/presentation of the findings in the draft final report could be improved to enhance clarity and overall impact.

Specific Recommendations for Improvement

The peer review panel had relatively few substantive recommendations for improvement: (a) that further analyses be conducted on (and that the final report focus more sharply on) the potential confounds and bias issues surrounding the 1- versus 2-day restart conditions, and (b) that, where possible, more emphasis be placed on within-subject statistical analyses. Remaining recommendations (detailed in the comments of the individual reviewers) focused primarily on (a) enhancing the manner in which the report is organized and the findings are presented; and (b) suggested edits to correct grammatical errors and typos.

SUMMARY OF PEER REVIEW COMMENTS:

Project Strengths:

1. Outstanding study team.
2. Near-flawless study execution/data quality despite severe time pressure.
3. Foresight of the study team reflected in the collection of data on "anticipated restart type" and "reason for anticipated restart type" which permits exploration of possible sources of selection bias.
4. Assessment of the heterogeneity of effects of restart type across diverse industry segments effectively revealed the complexity of this issue.

5. Although many additional analyses are possible, the findings that were presented were generally clear, thorough, and directly relevant to the study hypotheses.

Project Weaknesses:

1. Mandated constraints on the study design (i.e., constraints that were beyond the control of the study team).
2. The report should contain greater detail and/or clarity regarding how, and the extent to which, potential bias or confounding due to self-selection of 1- versus 2-day restart options were dealt with/controlled.
3. Better use of graphs and figures in the report is suggested to facilitate comprehension by non-scientific readers.
4. The 'recruitment via convenience' methodology utilized in the present study limits the extent to which the present findings may generalize to the U.S. CMV driver population.

Suggested Improvements:

1. Increased utilization of graphical displays in the report.
2. Inclusion of more analyses to determine the potential effects of self-selection of the 1- versus 2-day restart options.
3. Inclusion of more exploratory data analyses on outcome variables.
4. The report requires proofreading.

APPENDIX I—NUMBERS OF INCLUDED AND EXCLUDED SAMPLING UNITS FOR ANALYSIS PER DRIVER

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units Excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
1	1	9	0	9	0	9
2	1	11	0	11	0	11
3	1	12	0	12	0	12
4	1	1	0	1	0	1
5	1	4	1	3	0	3
6	1	3	0	3	3	0
7	1	9	0	9	0	9
8	1	5	0	5	0	5
9	1	2	0	2	0	2
10	1	9	1	8	0	8
11	1	22	1	21	0	21
12	1	5	0	5	5	0
13	1	10	1	9	0	9
14	1	2	1	1	0	1
15	1	3	0	3	3	0
16	1	9	0	9	0	9
17	1	11	3	8	8	0
18	1	6	0	6	0	6
19	1	11	0	11	6	5
20	1	2	1	1	0	1
21	1	4	0	4	0	4
22	1	5	0	5	5	0
23	1	21	0	21	0	21
24	1	9	0	9	0	9
25	1	22	1	21	0	21
26	1	14	2	12	6	6
27	1	10	1	9	1	8
28	1	8	0	8	0	8
29	1	13	0	13	0	13
30	1	10	0	10	0	10
31	1	3	1	2	0	2
32	1	22	1	21	0	21
33	1	1	0	1	0	1
34	1	14	0	14	11	3
35	1	6	0	6	0	6
36	1	12	0	12	0	12
37	1	21	0	21	1	20

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
38	1	8	0	8	0	8
39	1	6	0	6	0	6
40	1	13	5	8	0	8
41	1	2	1	1	0	1
42	1	2	0	2	1	1
43	1	7	0	7	0	7
44	1	3	0	3	0	3
45	1	8	0	8	1	7
46	1	6	0	6	0	6
47	1	14	3	11	8	3
48	1	24	1	23	1	22
49	1	21	1	20	0	20
50	1	22	0	22	0	22
51	1	22	1	21	1	20
52	1	17	1	16	0	16
53	1	6	0	6	0	6
54	1	16	2	14	0	14
55	1	20	2	18	0	18
56	1	21	0	21	0	21
57	1	18	7	11	0	11
58	1	2	1	1	1	0
59	1	22	1	21	0	21
60	1	22	1	21	0	21
61	1	24	1	23	1	22
62	1	19	0	19	0	19
63	1	21	0	21	5	16
64	1	23	1	22	0	22
65	1	2	1	1	0	1
66	1	23	1	22	0	22
67	1	22	0	22	0	22
68	1	21	0	21	0	21
69	1	17	1	16	0	16
70	1	22	1	21	0	21
71	1	16	1	15	0	15
72	1	23	1	22	0	22
73	1	5	0	5	0	5
74	1	4	0	4	0	4
75	1	18	1	17	0	17
76	1	18	0	18	0	18
77	1	22	0	22	0	22

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
78	1	22	0	22	0	22
79	1	24	1	23	2	21
80	1	14	1	13	0	13
81	1	23	1	22	0	22
82	1	23	1	22	0	22
83	1	22	0	22	1	21
84	1	22	1	21	0	21
85	1	22	1	21	0	21
86	1	14	0	14	0	14
87	1	21	0	21	0	21
88	1	18	2	16	3	13
89	1	2	0	2	0	2
90	1	21	5	16	0	16
91	1	4	0	4	0	4
92	1	4	0	4	0	4
93	1	4	0	4	0	4
94	1	12	1	11	0	11
95	1	8	0	8	0	8
96	1	18	3	15	0	15
97	1	21	2	19	6	13
98	1	24	2	22	0	22
99	1	19	0	19	0	19
100	1	10	1	9	0	9
101	1	22	0	22	0	22
102	1	10	1	9	9	0
103	1	12	0	12	1	11
104	1	21	0	21	0	21
105	1	22	3	19	6	13
106	1	4	0	4	0	4
107	1	18	0	18	0	18
108	1	11	0	11	0	11
109	1	8	0	8	0	8
110	1	15	2	13	0	13
111	1	4	0	4	0	4
112	1	19	1	18	0	18
113	1	13	3	10	0	10
114	1	5	2	3	0	3
115	1	6	1	5	0	5
116	1	12	0	12	0	12
117	1	10	1	9	4	5

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
118	1	2	1	1	0	1
119	1	21	0	21	0	21
120	1	10	1	9	8	1
121	1	29	12	17	4	13
122	1	3	0	3	0	3
123	1	13	5	8	0	8
124	1	21	0	21	0	21
125	1	19	0	19	13	6
126	1	18	3	15	1	14
127	1	27	5	22	5	17
128	1	25	2	23	6	17
129	1	24	2	22	1	21
130	1	10	0	10	2	8
131	1	10	3	7	0	7
132	1	20	0	20	5	15
133	1	25	2	23	0	23
134	1	22	4	18	2	16
135	1	23	3	20	8	12
136	1	3	1	2	0	2
137	1	19	0	19	0	19
138	1	24	3	21	0	21
139	1	3	0	3	0	3
140	1	22	3	19	1	18
141	1	15	3	12	0	12
142	1	19	5	14	0	14
143	1	11	1	10	0	10
144	1	22	7	15	3	12
145	1	13	4	9	0	9
146	1	4	2	2	0	2
147	1	12	0	12	0	12
148	1	22	0	22	15	7
149	1	16	2	14	0	14
150	1	21	3	18	3	15
151	1	11	0	11	6	5
152	1	22	1	21	0	21
153	1	20	3	17	0	17
154	1	17	0	17	0	17
155	1	3	0	3	0	3
156	1	22	5	17	0	17
157	1	15	7	8	0	8

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
158	1	26	11	15	4	11
159	1	26	4	22	4	18
160	1	20	1	19	0	19
161	1	22	0	22	1	21
162	1	23	2	21	0	21
163	1	17	1	16	3	13
164	1	19	0	19	0	19
165	1	18	1	17	7	10
166	1	19	0	19	0	19
167	1	10	0	10	0	10
168	1	2	0	2	2	0
169	1	26	5	21	0	21
170	1	20	1	19	0	19
171	1	22	0	22	0	22
172	1	21	4	17	5	12
173	1	23	2	21	0	21
174	1	16	0	16	0	16
175	1	23	0	23	1	22
176	1	17	1	16	0	16
177	1	16	4	12	0	12
178	1	4	0	4	0	4
179	1	21	2	19	0	19
180	1	21	0	21	0	21
181	1	22	1	21	0	21
182	1	21	1	20	0	20
183	1	21	1	20	0	20
184	0	1	1	0	0	0
185	1	23	3	20	0	20
186	1	23	3	20	0	20
187	1	22	0	22	0	22
188	1	21	0	21	0	21
189	1	21	1	20	0	20
190	1	20	0	20	0	20
191	1	21	1	20	0	20
192	1	20	0	20	0	20
193	1	19	0	19	0	19
194	1	23	1	22	1	21
195	1	9	1	8	8	0
196	1	5	0	5	0	5
197	1	4	0	4	0	4

Subject ID	Driver has at least 1 SU(t)	Total Number of Sampling Units Determined by Algorithm	Total Excluded Sampling Units	Total Included Sampling Units	Sampling Units excluded from SCE Analysis Set	Total Sampling Units Included in SCE Analysis Set
198	1	12	2	10	3	7
199	1	21	1	20	0	20
200	1	21	1	20	0	20
201	1	21	2	19	0	19
202	1	15	1	14	0	14
203	1	18	0	18	0	18
204	1	10	0	10	0	10
205	1	11	1	10	0	10
206	1	22	2	20	0	20
207	1	8	2	6	0	6
208	1	12	3	9	5	4
209	1	17	0	17	0	17
210	1	7	2	5	0	5
211	1	19	0	19	0	19
212	1	16	0	16	0	16
213	1	17	0	17	1	16
214	1	21	1	20	0	20
215	1	22	1	21	0	21
216	1	14	1	13	0	13
217	1	16	6	10	0	10
218	1	21	0	21	0	21
219	1	20	1	19	7	12
220	1	10	6	4	0	4
221	1	22	2	20	10	10
222	1	20	0	20	0	20
223	1	30	7	23	7	16
224	1	11	3	8	1	7
225	1	32	8	24	13	11
226	1	23	11	12	2	10
227	1	19	6	13	5	8
228	1	16	0	16	1	15
229	1	21	0	21	0	21
230	1	25	3	22	17	5
231	1	14	2	12	8	4
232	1	18	0	18	0	18
233	1	19	1	18	0	18
234	1	28	5	23	0	23
235	1	4	0	4	0	4
236	1	16	1	15	0	15
Total	**235**	**3,602**	**315**	**3,287**	**299**	**2,988**

APPENDIX J—EXCLUDED SAMPLING UNITS AND THE REASON(S) FOR EXCLUSION

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per Day in NR(t)	Length of Restart R(t) in Days
1	3.00	0.01	0.00	0.00	44.31
2	8.00	0.01	0.03	3.20	12.86
3	1.00	0.02	0.47	24.00	1.80
4	5.00	0.03	0.38	14.15	1.87
5	12.00	0.03	0.42	14.29	1.87
6	6.00	0.03	0.72	24.00	6.17
7	5.00	0.03	0.65	21.27	1.73
8	7.00	0.03	0.80	24.00	2.53
9	13.00	0.04	0.00	0.00	4.09
10	5.00	0.04	0.62	14.80	2.81
11	10.00	0.05	0.82	17.29	6.13
12	11.00	0.05	1.18	23.67	6.21
13	7.00	0.05	1.05	19.89	2.22
14	7.00	0.05	0.78	14.46	1.62
15	3.00	0.06	0.82	14.70	2.97
16	21.00	0.06	0.68	11.86	1.87
17	5.00	0.06	1.12	17.48	1.59
18	6.00	0.07	1.47	22.47	3.99
19	5.00	0.07	1.50	20.57	61.24
20	8.00	0.07	0.57	7.70	3.75
21	13.00	0.07	1.25	16.98	4.63
22	2.00	0.07	1.67	22.43	2.44
23	20.00	0.08	1.47	19.56	2.49
24	2.00	0.08	1.47	19.38	1.78
25	10.00	0.08	1.25	16.36	6.89
26	25.00	0.08	0.28	3.61	1.50
27	20.00	0.10	2.13	21.04	2.70
28	11.00	0.10	0.55	5.32	2.45
29	5.00	0.10	2.40	23.19	5.81
30	7.00	0.11	2.23	20.75	1.96
31	12.00	0.13	2.05	16.22	3.43
32	12.00	0.13	2.77	21.89	3.04
33	6.00	0.13	1.48	11.42	5.45
34	14.00	0.13	0.78	6.00	1.54
35	18.00	0.14	3.03	22.17	1.42
36	9.00	0.14	0.85	6.09	4.11
37	2.00	0.15	2.58	17.71	1.70
38	10.00	0.15	2.25	15.07	1.50
39	17.00	0.15	2.85	19.09	1.43

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
40	1.00	0.15	1.17	7.64	1.83
41	5.00	0.16	3.60	22.94	3.86
42	3.00	0.16	2.62	16.17	2.32
43	14.00	0.17	2.48	14.42	1.83
44	10.00	0.17	2.75	15.90	1.70
45	10.00	0.18	3.77	21.35	1.57
46	12.00	0.18	3.00	16.68	2.00
47	4.00	0.18	0.00	0.00	1.62
48	19.00	0.18	0.45	2.45	1.60
49	7.00	0.19	3.90	20.13	1.67
50	5.00	0.19	4.67	24.00	1.47
51	16.00	0.20	0.93	4.75	2.70
52	15.00	0.20	4.07	20.48	2.14
53	20.00	0.20	1.75	8.78	1.47
54	10.00	0.21	3.50	16.86	1.56
55	12.00	0.21	1.57	7.45	2.20
56	8.00	0.22	2.15	9.77	1.51
57	3.00	0.22	5.35	23.85	4.52
58	14.00	0.23	0.95	4.21	2.51
59	1.00	0.23	5.02	22.16	1.69
60	13.00	0.23	5.02	21.82	1.63
61	8.00	0.24	3.90	16.52	2.29
62	18.00	0.24	5.00	20.99	2.02
63	21.00	0.25	0.00	0.00	1.42
64	1.00	0.25	1.93	7.59	2.02
65	6.00	0.26	4.50	17.42	6.79
66	9.00	0.26	5.95	23.03	4.13
67	14.00	0.26	1.38	5.33	2.34
68	14.00	0.26	5.23	19.94	15.83
69	5.00	0.27	5.42	20.37	1.87
70	4.00	0.27	3.22	12.03	2.68
71	17.00	0.27	6.57	24.00	1.51
72	18.00	0.28	2.18	7.94	3.61
73	15.00	0.28	4.47	16.16	1.96
74	5.00	0.29	4.17	14.53	3.53
75	2.00	0.29	6.43	22.43	1.71
76	13.00	0.29	1.03	3.59	4.63
77	11.00	0.29	1.85	6.30	3.35
78	6.00	0.30	0.63	2.12	6.37
79	1.00	0.30	0.00	0.00	2.93
80	15.00	0.30	4.42	14.55	2.05
81	6.00	0.31	0.37	1.18	1.79
82	17.00	0.31	1.92	6.15	7.68

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
83	15.00	0.31	4.58	14.70	1.68
84	2.00	0.31	1.82	5.81	1.75
85	4.00	0.31	3.37	10.70	1.56
86	1.00	0.31	5.62	17.85	1.45
87	7.00	0.32	5.32	16.72	6.26
88	10.00	0.32	4.25	13.16	1.51
89	20.00	0.32	6.57	20.29	3.13
90	6.00	0.33	5.27	16.21	3.55
91	6.00	0.33	5.02	15.40	5.83
92	1.00	0.33	3.00	9.19	3.57
93	3.00	0.33	3.55	10.88	2.64
94	1.00	0.33	7.33	22.42	1.97
95	14.00	0.33	5.97	18.09	3.44
96	6.00	0.33	0.80	2.40	5.39
97	16.00	0.34	5.67	16.45	2.01
98	12.00	0.35	5.05	14.51	1.85
99	9.00	0.35	1.07	3.05	1.51
100	19.00	0.35	7.62	21.81	6.68
101	18.00	0.35	4.22	12.02	5.19
102	6.00	0.35	2.70	7.67	1.47
103	9.00	0.35	5.85	16.52	6.30
104	12.00	0.36	3.02	8.43	1.55
105	3.00	0.36	7.00	19.57	1.90
106	4.00	0.36	4.25	11.79	3.59
107	15.00	0.36	6.87	18.94	1.86
108	4.00	0.36	4.10	11.29	1.42
109	24.00	0.37	7.13	19.49	2.69
110	4.00	0.38	6.98	18.55	3.40
111	2.00	0.38	5.80	15.27	3.64
112	18.00	0.38	5.65	14.85	1.83
113	5.00	0.38	3.25	8.52	2.69
114	14.00	0.38	4.67	12.24	2.45
115	17.00	0.38	6.77	17.65	1.62
116	11.00	0.39	7.75	20.11	1.68
117	16.00	0.39	3.52	9.11	2.55
118	9.00	0.40	5.70	14.37	1.61
119	2.00	0.40	4.10	10.27	3.58
120	19.00	0.40	6.70	16.69	1.69
121	17.00	0.40	9.05	22.47	1.90
122	20.00	0.40	6.07	15.04	14.55
123	5.00	0.40	6.18	15.33	2.56
124	22.00	0.40	5.52	13.65	2.86
125	3.00	0.40	8.18	20.21	1.46

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
126	15.00	0.41	8.10	19.94	1.52
127	6.00	0.41	7.22	17.55	3.61
128	20.00	0.41	8.23	20.03	1.57
129	9.00	0.41	2.23	5.41	2.41
130	6.00	0.41	7.80	18.85	2.58
131	10.00	0.41	3.12	7.52	2.51
132	18.00	0.41	7.33	17.69	2.49
133	24.00	0.42	6.40	15.33	2.74
134	5.00	0.42	6.50	15.55	2.49
135	21.00	0.42	4.87	11.58	2.59
136	15.00	0.42	7.43	17.66	1.53
137	24.00	0.42	7.90	18.77	3.17
138	14.00	0.42	8.82	20.88	1.70
139	14.00	0.42	8.38	19.82	2.49
140	24.00	0.43	0.57	1.33	1.56
141	16.00	0.43	8.52	19.94	1.69
142	15.00	0.43	2.07	4.81	2.56
143	8.00	0.43	4.25	9.87	3.04
144	12.00	0.43	7.32	16.99	2.60
145	1.00	0.43	8.57	19.80	1.47
146	20.00	0.43	2.97	6.82	1.56
147	5.00	0.43	7.27	16.72	1.52
148	2.00	0.44	7.30	16.74	2.98
149	1.00	0.44	1.90	4.34	1.86
150	14.00	0.44	2.13	4.87	2.58
151	4.00	0.44	6.48	14.77	2.18
152	3.00	0.44	1.37	3.09	2.59
153	7.00	0.44	4.05	9.14	1.52
154	9.00	0.44	8.92	20.13	9.58
155	22.00	0.45	5.73	12.88	2.30
156	4.00	0.45	7.50	16.85	2.51
157	18.00	0.45	8.87	19.89	1.63
158	5.00	0.45	4.83	10.76	4.48
159	27.00	0.45	5.90	13.07	1.50
160	7.00	0.45	6.88	15.25	3.50
161	14.00	0.45	7.85	17.39	5.91
162	10.00	0.45	2.02	4.46	2.55
163	14.00	0.46	0.00	0.00	1.58
164	9.00	0.46	3.62	7.93	3.60
165	8.00	0.46	10.10	22.14	2.04
166	7.00	0.46	4.42	9.61	1.58
167	4.00	0.46	9.22	19.96	1.53
168	12.00	0.46	9.32	20.17	1.68

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
169	6.00	0.46	8.25	17.84	3.60
170	2.00	0.46	9.43	20.40	3.71
171	20.00	0.46	5.70	12.29	1.63
172	9.00	0.46	9.17	19.76	2.58
173	1.00	0.47	1.00	2.14	3.52
174	4.00	0.47	1.18	2.54	1.55
175	18.00	0.47	7.52	16.08	1.50
176	3.00	0.47	9.43	20.09	1.51
177	4.00	0.47	9.68	20.63	1.57
178	12.00	0.47	9.60	20.42	1.52
179	17.00	0.47	9.18	19.45	2.01
180	16.00	0.48	6.05	12.72	4.58
181	7.00	0.48	6.65	13.98	1.53
182	20.00	0.48	6.85	14.40	1.43
183	14.00	0.48	10.45	21.90	12.04
184	15.00	0.48	10.67	22.33	1.62
185	5.00	0.48	7.05	14.69	1.63
186	22.00	0.48	7.95	16.52	2.39
187	8.00	0.49	3.22	6.63	3.33
188	2.00	0.49	6.10	12.48	1.51
189	18.00	0.49	5.58	11.36	2.02
190	6.00	0.49	7.27	14.76	1.51
191	15.00	0.50	3.23	6.53	1.51
192	19.00	0.50	4.73	9.55	2.64
193	7.00	0.50	9.68	19.34	2.42
194	7.00	0.50	8.13	16.22	29.16
195	12.00	0.50	6.62	13.18	2.15
196	25.00	0.51	4.83	9.53	3.23
197	11.00	0.51	10.72	21.14	2.35
198	23.00	0.51	0.93	1.84	1.42
199	3.00	0.51	0.07	0.13	2.51
200	12.00	0.51	6.75	13.17	1.59
201	10.00	0.51	6.22	12.10	1.84
202	1.00	0.51	1.60	3.11	4.51
203	5.00	0.51	3.33	6.48	4.13
204	16.00	0.51	8.52	16.55	1.57
205	1.00	0.52	6.23	12.08	2.00
206	7.00	0.52	5.37	10.39	1.78
207	4.00	0.52	9.62	18.44	1.50
208	10.00	0.53	3.75	7.12	3.70
209	8.00	0.53	5.12	9.67	2.38
210	23.00	0.53	1.87	3.51	2.46
211	11.00	0.54	2.63	4.92	2.82

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
212	2.00	0.54	8.58	15.95	2.51
213	22.00	0.54	4.05	7.52	2.57
214	11.00	0.54	9.90	18.37	1.44
215	4.00	0.54	8.98	16.63	1.48
216	21.00	0.54	9.83	18.11	2.47
217	4.00	0.54	5.70	10.47	80.47
218	4.00	0.54	6.98	12.83	3.06
219	24.00	0.55	8.03	14.74	1.45
220	14.00	0.55	11.00	20.05	2.60
221	3.00	0.55	1.38	2.52	2.55
222	2.00	0.55	9.68	17.52	1.60
223	5.00	0.55	13.13	23.76	9.92
224	1.00	0.55	8.03	14.50	3.22
225	14.00	0.56	9.15	16.43	2.45
226	5.00	0.56	10.60	18.89	2.05
227	12.00	0.56	3.45	6.13	2.35
228	10.00	0.56	4.98	8.83	1.43
229	12.00	0.57	6.03	10.63	2.54
230	11.00	0.57	6.38	11.24	2.43
231	19.00	0.57	11.07	19.39	1.42
232	2.00	0.57	1.42	2.48	1.43
233	1.00	0.57	2.00	3.49	1.52
234	1.00	0.57	2.37	4.13	2.19
235	22.00	0.58	8.67	15.02	1.58
236	12.00	0.58	9.80	16.96	2.03
237	6.00	0.58	10.10	17.48	2.51
238	2.00	0.58	3.45	5.95	2.86
239	15.00	0.58	10.68	18.42	3.58
240	16.00	0.58	9.82	16.87	1.43
241	18.00	0.58	2.28	3.91	1.56
242	8.00	0.58	5.87	10.03	2.05
243	16.00	0.59	9.03	15.41	2.18
244	7.00	0.59	8.97	15.19	3.44
245	22.00	0.59	3.55	5.99	3.44
246	10.00	0.60	9.57	15.98	4.86
247	21.00	0.61	1.35	2.23	1.62
248	1.00	0.61	1.77	2.89	4.47
249	18.00	0.61	6.22	10.16	1.87
250	13.00	0.65	3.30	5.07	2.54
251	7.00	0.65	6.22	9.52	2.31
252	7.00	0.66	12.55	19.08	3.62
253	2.00	0.66	6.00	9.10	2.68
254	7.00	0.67	7.25	10.88	3.15

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
255	19.00	0.67	6.60	9.88	1.55
256	2.00	0.68	11.55	16.95	12.96
257	10.00	0.70	0.00	0.00	4.83
258	6.00	0.71	10.93	15.44	6.05
259	13.00	0.78	2.87	3.70	1.99
260	9.00	0.82	7.13	8.75	3.57
261	4.00	0.82	9.35	11.46	3.76
262	16.00	0.84	10.28	12.23	2.81
263	1.00	0.85	7.78	9.19	3.82
264	6.00	0.92	10.15	11.05	1.50
265	12.00	0.93	6.17	6.60	15.48
266	1.00	0.95	4.58	4.84	2.65
267	17.00	0.96	11.30	11.72	2.50
268	5.00	0.98	17.10	17.45	5.56
269	19.00	0.99	0.00	0.00	2.83
270	22.00	0.99	8.70	8.79	2.03
271	16.00	1.03	0.63	0.62	2.57
272	6.00	1.03	1.40	1.35	7.86
273	11.00	1.09	0.80	0.73	4.03
274	13.00	1.14	2.75	2.41	1.66
275	29.00	1.16	2.97	2.56	2.33
276	24.00	1.27	3.95	3.11	2.63
277	15.00	1.33	0.00	0.00	1.50
278	13.00	1.35	3.40	2.53	1.83
279	8.00	1.42	1.87	1.32	2.80
280	17.00	1.44	3.85	2.68	2.70
281	6.00	1.45	3.35	2.30	2.40
282	15.00	1.46	0.00	0.00	2.46
283	26.00	1.48	3.72	2.51	1.95
284	9.00	1.50	2.22	1.48	1.53
285	9.00	1.52	2.73	1.80	1.64
286	7.00	1.53	2.05	1.34	1.45
287	16.00	1.56	2.42	1.55	9.53
288	3.00	1.66	3.63	2.19	1.51
289	23.00	1.91	3.68	1.93	2.37
290	8.00	2.03	1.20	0.59	1.74
291	2.00	2.18	2.08	0.96	1.84
292	12.00	2.25	2.40	1.07	2.58
293	19.00	2.26	3.75	1.66	6.63
294	1.00	2.48	3.78	1.52	2.52
295	4.00	2.53	3.73	1.48	2.56
296	19.00	2.54	3.32	1.30	2.00
297	17.00	2.83	0.00	0.00	2.83

Observation	SU(t)	Length of Non-Restart NR(t) in Days	Sum Driving Hours in NR(t)	Mean Driving Hours per day in NR(t)	Length of Restart R(t) in Days
298	2.00	2.96	0.00	0.00	1.42
299	19.00	3.42	0.52	0.15	2.08
300	1.00	3.73	0.00	0.00	2.04
301	11.00	4.20	3.25	0.77	4.05
302	12.00	4.30	2.73	0.64	2.90
303	1.00	4.30	21.83	5.08	87.53
304	11.00	4.40	2.35	0.53	1.74
305	11.00	4.43	2.23	0.50	2.60
306	15.00	5.40	3.40	0.63	1.49
307	7.00	5.57	1.75	0.31	3.83
308	5.00	5.60	3.45	0.62	1.60
309	1.00	6.43	0.00	0.00	1.44
310	3.00	6.69	62.17	9.29	88.88
311	13.00	8.18	1.38	0.17	3.92
312	6.00	9.96	3.32	0.33	2.01
313	4.00	14.00	2.02	0.14	6.41
314	4.00	14.00	316.6	22.61	2.68
315	6.00	14.00	323.6	23.12	1.65

APPENDIX K—STATISTICAL MODELING METHODS

MIXED-EFFECTS STATISTICAL MODELS

Formal statistical comparisons among expected outcomes on the basis of provision use were performed using linear and non-linear mixed-effects modeling. The objectives of using the mixed modeling approach are:

1. To reduce bias and potential confounding arising from the observational naturalistic study design by producing estimated means and differences in means adjusting for an *a priori* set of covariates.
2. To adequately account for correlations among outcomes from sampling units from the same driver and among multiple outcomes observed within the same sampling unit. Unless such correlations are adequately accounted for, there can be inflation of type 1 error when testing hypotheses.

The linear mixed-effects model for continuous outcomes[126,127] can be expressed as:

$$\mathbf{Y_i = X_i\beta + Z_iu + e_i}$$

The 'fixed' part of this model involves the terms $\mathbf{X_i\beta}$. $\mathbf{X}$ is a design matrix for the fixed effects. $\boldsymbol{\beta}$ is the set of parameters to be estimated including provision use factors and the set of covariates. The predicted mean values under each provision condition as well as differences in mean values were estimated as a function of estimates of $\boldsymbol{\beta}$. The remaining parts of the model reflect "random effects." Random effects are used to account for correlations among measurements taken from the same driver and for additional correlations among multiple outcomes measured within the same sampling unit (when applicable). Random effects can be accounted for by the $\mathbf{u}$ terms in the above model or by specifying special structure for the covariance matrix of the error terms $\mathbf{e}$. This latter approach is especially applicable for longitudinal data. Generally speaking, the expected values of random effects are equal to zero. This permits all hypotheses of interest to be specified in terms of estimated $\boldsymbol{\beta}$'s. The various models for random effects impact on estimated standard errors of model parameters of interest. The random effects used in models are described below. Generalized linear mixed models[128] were used to assess outcomes expressed as counts (PVT-B lapses per 3-minute test) or rates (SCEs).

MODEL COVARIATES

Every model included the following primary factors:

- Number of restart nights (1 night versus 2 nights versus >2 nights)
- Use of the 168-hour provision (<168 hours versus ≥168 hours versus 1st sampling unit). The "1st sampling unit level" for this factor was needed to avoid excluding all first sampling units. This is because classifying sampling units by the 168-hour provision depends on the time between the start of the prior restart period to next restart period, which is unknown for the first sampling unit.

- Restart nights by 168-hour provision interaction. The interaction term was included in the model to allow for the effects of one provision on outcomes to vary according to use of the other. However, the focus of estimation was on the main effects of provision use.

Baseline Covariates

Every mixed-effects model included an *a priori* set of covariates that was specified in Table 1 of the study plan. These covariates included both baseline variables and sampling unit specific variables. Restricting attention to an *a priori* set of covariate reduces bias and helps to control Type 1 error.

There were 2 continuous baseline covariates included in the models. These variables were:

- Driver age.
- Driver BMI.

There were 10 categorical baseline variables. These were:

- Driver in Fatigue Management Program (No, Yes, Unsure).
- Gender (male versus female).
- Marital status (married yes versus no).
- Diabetes (yes versus no).
- High blood pressure (yes versus no).
- Insomnia (yes versus no).
- Sleep apnea (yes versus no).
- Driver pain experience (0–5 percent, 5–25 percent, 25–50 percent, 50–75 percent, ≥75percent). The last two categories were combined in the models due to the small number of drivers reporting ≥75 percent pain.
- Use of caffeine.
- Use of tobacco.

Sampling Unit Specific Covariates

In addition to the baseline variables, there were two categorical factors related to driver expectations regarding their next use of the provisions. These factors were obtained from weekly calls made during the non-restart duty cycles.

These 2 factors were:

- For upcoming restart—planned number of nights off? ("Planning 1 Night Next Restart" versus "Planning ≥2 Nights Next Restart" versus "Missing").

- Next restart—night off rationale? (“Largely Due to Federal Regulations” versus “Largely My Company’s Decision” versus “Largely My decision, but Based on Personal Preference” versus “Largely My Decision, but Based on Work Requirements” versus “Missing”).

In cases when there was more than one call prior to a restart, the responses closest to the restart were chosen. In cases when there were no calls prior to a specific restart, a last observation carried forward approach was taken, and the responses from prior restarts closest to the sampling unit in question were used. There was a small percentage of sampling units, often including the first sampling unit, in which there was no prior weekly call. In these cases, the categorical variables were given levels of “Missing” in order to avoid excluding sampling units.

Time-of-Day

Models for outcomes collected multiple times per day included a time-of-day factor defined according to home terminal time:

- 12 a.m. to 3:59 a.m.
- 4 a.m. to 7:59 a.m.
- 8 a.m. to 11:59 a.m.
- 12 p.m. to 3:59 p.m.
- 4 p.m. to 7:59 p.m.
- 8 p.m. to 11:59 p.m.

Inclusion of a six-level time-of-day factor was designed to account for variability associated with circadian effects on outcomes.

DEFINING THE TARGET POPULATION FOR ESTIMATING MEAN VALUES

The mixed-effects models were used to estimate population mean values of outcomes under the following sets of condition reflecting provision use:

- 1-night restart.
- 2-night restart.
- >2-night restart.

And for:

- <168 hours between restarts.
- ≥168 hours between restarts.
- 1st sampling unit.

When estimating predicted mean values for each level of provision use, it is necessary to specify precisely for whom these predicted mean values apply. For this study, predicted mean values were determined for a target population that reflected the covariate distributions observed in the collection of sampling units. The model formulation used to accomplish this are discussed in the following sections.

Coefficients for Covariates

By default, the SAS procedures MIXED and GLIMMIX determine predicted mean values that assume that continuous covariates are equal to the sample mean. For age and BMI, the mean values are 46.085 years and 32.418 k/m^2, respectively. Therefore, predicted mean values under the various categories of provision use are for drivers who are about 46.1 years old with BMI equal to about 32.4 k/m^2. It is noteworthy that this applies to predicted mean values. When estimating differences among provision use categories, age and BMI effects, as well as the effects of all of the covariates, are not involved.

In contrast to continuous variables, the SAS default is to assume that each level of categorical variables (included in a class statement) are equally represented in the population. Thus, this default leads to distorted predicted means if the levels in the target population are not equally likely. For example, there were relatively few women contributing sampling units in this study and so assuming an equally likely distribution of males and females would result in distorted predicted mean values across provision use categories for any outcome that is associated with gender.

To address this issue, all control factors were represented in the model as a set of 0-1 numeric indicator variables. This is in contrast to the modeling these as qualitative factors by including them in the SAS "class" statement. This approach permitted specification of coefficients designed to reflect the relative proportions observed in the sample. In this way, the predicted mean values are designed to reflect a population that mimics the sample population.

Figure 10 indicates the **X** variables for each indicator variable used in the model:

$\mathbf{Y_i = X_i\beta + Z_i u + e_i.}$

Exhibit A: Coefficients for Control Variables

DRV_BMI	32.4175225	
DRV_AGE	46.0851944	
NRC1	0.1058726	*/
NRC2	0.1861042	
NRC3	0.3097601	
NRC4	0.3056245	
NRCM	0.0926385	
PNNR1	0.1881720	*/
PNNR2	0.7142266	
PNNRM	0.0976013	
DRV_FMP0	0.8908189	*/
DRV_FMP1	0.0818859	
DRV_FMP2	0.0272953	
MALE	0.9321754	
MARRIED	0.6058726	
DIABETES	0.0748553	
HBP	0.2241522	
INSOMNIA	0.0095120	
APNEA	0.1228288	
CAFF	0.9243176	
TOB	0.4441687	

Figure 10. Exhibit A: Coefficients for control variables.

The first level of factors with more than two levels is commented out and so is not included in the mode. These are not needed in the estimation since they are redundant. Although the predicted mean results are the same with or without commenting out the redundant levels, type III p-values for the covariates do not appear in the SAS output documenting the results unless the redundant level indicators are excluded. Although it was beyond the scope of this study to interpret the statistical or substantive significance of associations between covariates and outcomes, the SAS documentation output file would indicates zero degrees of freedom with no p-values listed. This would look strange but would not otherwise impact on resulting pertaining to provision use.

The coefficients listed above are simply the sample proportions for these levels of the covariates in the collection of included sampling units. NRC1, NRC2, NRC3, NRC4, and NRCM refer to "Next Restart Cause" with 1="Largely Due to Federal Regulations"; 2= "Largely My Company's Decision"; 3="Largely My Decision, but Based on Personal Preference"; 4="Largely My Decision, but Based on Work Requirements"; and M= "Missing." The first level was arbitrarily made reference. Similarly, PNNR1, PNNR2, and PNNRM refer to the 3 levels of "Planned Number of Nights in Next Restart" equal to 1, ≥2, or "missing," respectively, with the first level arbitrarily selected as reference. Finally, DRV_FMP0, DRV_FMP1, and DRV_FMP2 refer to driver participation in a Fatigue Management Program with 0, 1, and 2 referring "No," "Yes," and "Unsure," respectively, with the "No" level arbitrarily serving as reference.

Coefficients for Time-of-Day Effects

Outcomes observed during the non-restart period and the restart period were always modeled separately. It was observed that the distribution of times-of-day for driver reported subjective ratings and PVT-B outcomes differed between the non-restart and restart follow-up periods. Therefore, to more accurately determine predicted mean values, different sets of coefficients were used for models involving non-restart outcomes and for models involving outcomes observed during restart periods (Figure 11).

Exhibit B: Coefficients for Time-of-Day Variables
Non-Restart coefficients: time_of_day_home .0858 .1749 .1377 .1708 .1786 .2522
Restart coefficients: time_of_day_home .0431 .1205 .1694 .1769 .1731 .3170

Figure 11. Image. Exhibit B: Coefficients for time-of-day variables.

These coefficients correspond to the times-of-day listed above. It is readily apparent that there were relatively fewer outcomes observed between 12–4 a.m. and 4–8 a.m. during non-restart duty cycles compared to restart periods (4.3 percent versus 8.9 percent and 12.1 percent versus 17.5 percent, respectively).

Coefficients for One Provision When Estimating the Mean Values for the Other

Finally, when determining the predicted mean values for 1-night, 2-night, and > 2-night restarts, it was similarly necessary to properly weight the coefficients for the 168-hour provision indicator variables. This is especially important since otherwise, the predicted mean values would reflect a population in which one-third of the sampling units were first sampling units, which is known to be false. Therefore, when estimating mean values for 1-night, 2-night, and > 2-night restarts, the following 168-hour provision coefficients were used:

- .065
- .451
- 0.484

These coefficients reflect the proportion of first restarts, restarts within 168 hours of the prior restart, and restarts occurring ≥168 hours from the prior restart, respectively.

Correspondingly, when estimating mean values for the 168-hour provision categories, the following coefficients were used for the number of nights of restart.

- .13
- .48
- .39

As noted above, a fixed effect for the interaction between number of restart nights and time between restarts was included in model. The above coefficients were also used for the contribution of these interactions to the predicted mean values across the provision use factors.

LINEAR COMBINATIONS OF MODEL PARAMETERS FOR PREDICTED MEANS BY PROVISION USE

The parameters of the model $\mathbf{Y_i = X_i\beta + Z_iu + e_i}$ were estimated using restricted maximum likelihood (REML). The estimates include a set of parameter estimates for $\boldsymbol{\beta}$.

Figure 12 shows the linear combinations of model parameters were therefore used to estimate predicted mean values.

```
•  estimate 'R1'   intercept 1 restart 1  0 0  p168 .065  .451
   0.484  restart*p168 .065  .451  0.484 0  0  0 0 0 0
   EXHIBIT_B EXHIBIT_A / divisor=1;
•  estimate 'R2'    intercept 1 restart 0  1 0  p168 .065  .451
   0.484  restart*p168 0  0 0  .065  .451  0.484  0 0 0
   EXHIBIT B EXHIBIT A / divisor=1;
•  estimate 'R>2'   intercept 1 restart 0  0 1  p168 .065  .451
   0.484    restart*p168 0 0 0 0 0  0    .065  .451    0.484
   EXHIBIT_B EXHIBIT_A / divisor=1;
•  estimate '1st SU' intercept 1 restart .13 .48 .39  p168 1 0 0
   restart*p168 .13  0  0 .48   0     0   .39    0       0
   EXHIBIT B EXHIBIT A / divisor=1;
•  estimate '<168'   intercept 1 restart .13 .48 .39  p168 0 1 0
   restart*p168  0   .13     0   0  .48     0     0    .39     0
   EXHIBIT_B EXHIBIT_A / divisor=1;
•  estimate '>=168'  intercept 1 restart .13 .48 .39  p168 0 0 1
   restart*p168    0  0   .13   0    0   .48     0    0   .39
   EXHIBIT_B EXHIBIT_A / divisor=1;
```

Figure 12. Image. Linear combinations of model parameters used to estimate the predicted mean values.

Where EXHIBIT_B and EXHIBIT_A in Figure 12 are the sets of coefficients for the time-of-day effects (where applicable) and covariate effects as defined above. For EXHIBIT B, either the coefficients for the non-restart period or the coefficients for restart period were used as appropriate.

LINEAR COMBINATIONS OF MODEL PARAMETERS FOR PROVISION USE COMPARISONS

Figure 13 shows the linear combinations of model parameters were used to estimate differences in means by provision use and to determine p-values for testing the null hypotheses of no difference in means by provision use. The coefficients in Exhibits A and B cancel out when estimating mean differences and so do not appear in the linear combination of model parameters.

```
• estimate 'R1 minus R2' intercept 0 restart 1 -1 0  p168 0 0 0   restart*p168
  .065  .451    0.484  -.065  -.451   -0.484  0 0 0  / divisor=1 ;
• estimate  'R1  minus  R>2'  intercept  0  restart  1  0  -1   p168  0  0  0
  restart*p168 .065  .451  0.484    0 0 0 -.065  -.451   -0.484 / divisor=1;
• estimate  'R2  minus  R>2'   intercept  0  restart  0   1  -1   p168  0  0  0
  restart*p168 0 0 0  .065  .451 0.484  -.065  -.451  -0.484 / divisor=1 ;
• estimate 'R1 minus (R2+R>2)/2' intercept 0 restart 2 -1 -1  p168 0 0 0
  restart*p168 .130 .902 0.968 -.065 -.451 -0.484 -.065 -.451 -0.484
  /divisor=2 ;
• estimate '<168 minus >=168'   intercept 0 restart 0 0 0   p168 0 1 -1
  restart*p168 0 .13 -.13   0  .48  -0.48  0    .39   -.39  / divisor=1 ;
```

Figure 13. Image. Linear combinations of model parameters used to estimate differences in means.

The fourth estimate statement in Figure 13 tests the null hypothesis that predicted mean values for restarts with 1 night is equal to the average of the predicted mean values for restarts with 2 nights and for restarts with more than 2 nights.

RANDOM EFFECTS

Random effects are included in mixed linear models to account for correlations among outcomes from the same driver. There are many ways to include random effects in mixed-effects linear models. Unless such correlations are adequately accounted for, there can be inflation of type 1 error when testing hypotheses. However, it was beyond the scope of the current analysis to precisely characterize random effects. Rather, the goal was to specify relatively simple random effects structure likely to adequately reduce type 1 error when testing hypotheses.

The models used for this study can be classified into two types. The first type was for outcomes that were observed multiple times within a single sampling unit. These outcomes included the five subjective ratings derived from the smartphone during the non-restart periods,three subjective ratings derived from the smartphone during the restart periods, PVT-B mean reciprocal response time during the non-restart and restart periods, as well as PVT-B total lapses during the non-restart and restart periods. Other outcomes were defined for the entire non-restart or restart periods. These included sleep estimates, sleep quality estimates, and outcomes determined from the ELD data.

Multiple Observations per Sampling Unit

There are a number of ways to account for ‘extra’ correlation among multiple observations within a sampling unit in conjunction with correlations among observations from the same driver.

One approach is to model correlations among outcomes within a sampling unit considering these as longitudinal data. For this purpose, a ‘sequence’ ID was defined within each sampling unit for all outcomes measured during a specific non-restart or restart period. This allows the ‘extra’ correlation over and above that induced by random driver effects to be modelled as repeated measures and reflected in the covariance matrix of the $\mathbf{e_i}$ residual error terms. The simplest of such models assumes “compound symmetry.” Compound symmetry assumes that the all correlations among any pair of observations within a sampling unit are equal. In conjunction with compound symmetry, this model also includes a ‘random intercept’ term to reflect correlation among all outcomes within driver whether or not these came from the same sampling unit. The between-driver random effect is designated as **u** in the model formulation above and is assumed to be normally distributed with mean zero and some variance that is estimated along with the fixed effects.

The following SAS statements are used to generate this random effects structure:

- random intercept / subject=sid ;
- repeated SUBJ_SEQ_NUM /subject = sid_su type=cs ;

It turns out that the same inferences can be made with an alternative model that includes two random effects in **u** but no longitudinal effect in **e**. The SAS statement to generate this random effects structure is:

- random sid sampling_unit(sid);

The random effect ‘sid’ (subject identification) is essentially the same as the random intercept term in the first formulation. The potential for ‘extra’ correlation among outcomes within the same sampling unit is accounted for by the nested random effect for sampling unit within driver.

It is important to note that the correspondence between these two models only arises when assumption compound symmetry. More complex covariance structures for **e** are possible including those that specify how correlations attenuate as the time (or distance) increases. However, it was felt that that inclusion of two sources of correlation would be sufficient to meet the objective of adequately accounting for correlations among outcomes from sampling units from the same driver and among multiple outcomes observed within the same sampling unit for the purpose of making comparisons among predicted means by provision use.

Both of these models were applied to the eight subjective rating outcomes and results were identical. However, when applied to the PVT-B outcomes, the repeated measures model formulation resulted in model ‘convergence’ errors while using the strictly random effects models could be estimated with no such error. Therefore, the second model formulation was used for all outcomes other than the subjective ratings outcomes.

Outcomes Defined Over the Entire Sampling Unit

For outcomes defined over the entire sampling unit such as outcomes derived from the ELD as well as for sleep determinations and sleep quality determinations, the random effects included only the between driver factors as well as residual error. For the sleep quality measure only, multiple assessments within each sampling unit (separately for Restart and Non-Restart periods) were averaged for consistency with determinations of actual sleep through actigraphy which were defined for the entire sampling unit.

SUMMARY OF SAS CODE FOR LINEAR MIXED MODELS

Figure 14 shows the essential SAS code for estimating the linear mixed effects models using in this study.

```
%macro linear_mixed(db,outcome, model_title);

title4 "&model_title";
ods proclabel "&model_title";
ods output lsmeans = estimated_means;
ods output diffs = differences_btn_means;
ods output estimates = sample_wtd_estimates ;

proc mixed data=&db order = internal  ;
class restart p168 sid sampling_unit   TIME_OF_DAY_HOME;
model  &outcome = restart p168 restart*p168 TIME_OF_DAY_HOME &cov_model  / ddfm =
satterthwaite solution;
random sid sampling_unit(sid) ;
lsmeans restart p168  /  diffs e ;
lsmeans restart*p168 ;
lsmeans TIME_OF_DAY_HOME ;

then contrast statements
then Exhibit B (for models with models with multiple outcomes per sampling unit)
then Exhibit A
then some statements to print out estimates in a convenient table format
%mend;

%linear_mixed(db=ratings_r,outcome=q2_my_stress,model_title=Linear Mixed Model for
Perceived Stress in R(t));
%linear_mixed(db=ratings_r,outcome=q3_my_fatigue,model_title=Linear Mixed Model for
Fatigue Scale in R(t));
%linear_mixed(db=ratings_r,outcome=q4_how_sleepy,model_title=Linear Mixed Model for KSS in
R(t));
```

Figure 14. Image. Essential SAS code for estimating the linear mixed-effects models.

NON-LINEAR MIXED MODELS

For the two generalized mixed-effects models, the SAS procedure GLMMIX was used. For PVT-B total lapses, the version of the model that included the nested effect for sampling unit was used. The only other adjustments needed were the inclusion of "dist=poisson" to indicate the assumption that total lapses per 3-minute trial follow a Poisson distribution rather than a Gaussian distribution. Preliminary graphical analyses of total lapses clearly demonstrated that the Poisson assumption was valid while the Gaussian assumption was not. Preliminary attempts to identify a 'normalizing' transformation were not successful. Therefore, it was decided to model the total lapses using the Poisson distribution. The other required addition was the 'ilink' (inverse link) option in the estimate statements. This was needed to produce predicted mean values on the original total lapses per 3-minute trial scale.

For modeling of SCE, the distribution was assumed to be negative binomial (dist=negbin) rather than Poisson to increase model flexibility in handling variability among drivers and sampling units. Additionally, the model accounted for variability in time exposed to SCEs. This was accomplished by including a term for number of 'instrumented' driving hours. As described elsewhere, instrumented driving hours refers to times in which available information contained no indication that the OBMS was non-operational. Exposure time was done by adding an offset statement with the offset defined as the sum of instrumented hours after dividing by 100 (offset= SUM_ELD_DRIVING_I_NR).

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APPENDIX L—POOLABILITY ANALYSES FOR THE EFFECTS OF PROVISIONS

Table 45. Analysis of poolability among industry segments: self-reported difficulty of drive (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.00004	0.0285	2056	0.00	0.9988
Regional (101–250 miles)	-0.04649	0.0453	542	-1.03	0.3057
Short-haul (≤100 miles)	0.07557	0.0703	200	1.08	0.2834
Large (>500 power units)	-0.02860	0.0323	1368	-0.88	0.3764
Medium (51–500 power units)	-0.05718	0.0351	1098	-1.63	0.1032
Small (1–50 power units)	0.16960	0.0681	348	2.49	0.0132*
Dry-van	-0.02173	0.0285	1670	-0.76	0.4455
Flat-bed	-0.02687	0.0487	498	-0.55	0.5811
Refrigerated	-0.06369	0.0560	414	-1.14	0.2560
Tanker	0.32300	0.1264	145	2.56	0.0116*

*Statistically significant difference at .05 level.

Table 46. Analysis of poolability among industry segments: self-reported difficulty of drive (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.00514	0.0156	1998	0.33	0.7421
Regional (101–250 miles)	0.01494	0.0339	537	0.44	0.6595
Short-haul (≤100 miles)	0.10390	0.0593	205	1.75	0.0812
Large (>500 power units)	-0.00203	0.0200	1299	-0.10	0.9193
Medium (51–500 power units)	0.01777	0.0201	1070	0.89	0.3756
Small (1–50 power units)	0.03674	0.0441	340	0.83	0.4054
Dry-van	0.02351	0.0170	1630	1.39	0.1662
Flat-bed	-0.00592	0.0245	496	-0.24	0.8092
Refrigerated	-0.00547	0.0403	391	-0.14	0.8920
Tanker	0.32300	0.1264	145	2.56	0.0116*

*Statistically significant difference at .05 level.

Table 47. Analysis of poolability among industry segments: self-reported driving hazards (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.02562	0.0329	2048	-0.78	0.4363
Regional (101–250 miles)	-0.01811	0.0510	532	-0.35	0.7228
Short-haul (≤100 miles)	0.02068	0.0570	201	0.36	0.7173
Large (>500 power units)	-0.00787	0.0357	1379	-0.22	0.8256
Medium (51–500 power units)	-0.11820	0.0401	1103	-2.94	0.0033*
Small (1–50 power units)	0.11420	0.0761	338	1.50	0.1343
Dry-van	-0.05048	0.0322	1676	-1.57	0.1176
Flat-bed	0.00967	0.0534	473	0.18	0.8564
Refrigerated	-0.05712	0.0614	436	-0.93	0.3529
Tanker	0.29600	0.1470	140	2.01	0.046*

*Statistically significant difference at .05 level.

Table 48. Analysis of poolability among industry segments: self-reported driving hazards (restarts taken in less than168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.00719	0.0181	1989	0.40	0.6905
Regional (101–250 miles)	0.01629	0.0381	528	0.43	0.6695
Short-haul (≤100 miles)	0.07615	0.0483	208	1.58	0.1160
Large (>500 power units)	0.01871	0.0221	1308	0.85	0.3974
Medium (51–500 power units)	0.00415	0.0230	1075	0.18	0.8566
Small (1–50 power units)	0.02825	0.0493	330	0.57	0.5671
Dry-van	0.03525	0.0192	1637	1.83	0.0667
Flat-bed	-0.00921	0.0269	471	-0.34	0.7321
Refrigerated	-0.03608	0.0442	413	-0.82	0.4148
Tanker	-0.06019	0.1026	137	-0.59	0.5584

*Statistically significant difference at .05 level.

Table 49. Analysis of poolability among industry segments: self-reported SS during duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.01837	0.0323	2098	-0.57	0.5691
Regional (101–250 miles)	-0.01261	0.0420	559	-0.30	0.7643
Short-haul (≤100 miles)	-0.02149	0.0605	176	-0.36	0.7230
Large (>500 power units)	0.01384	0.0312	1404	0.44	0.6569
Medium (51–500 power units)	-0.07149	0.0404	1118	-1.77	0.0774
Small (1–50 power units)	-0.03010	0.0808	362	-0.37	0.7098
Dry-van	-0.03010	0.0808	362	-0.37	0.7098
Flat-bed	-0.00644	0.0542	479	-0.12	0.9055
Refrigerated	-0.12880	0.0482	384	-2.67	0.0079*
Tanker	0.15440	0.0911	147	1.69	0.0923

*Statistically significant difference at .05 level.

Table 50. Analysis of poolability among industry segments: self-reported SS during duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.00635	0.0178	2034	0.36	0.7206
Regional (101–250 miles)	0.00278	0.0314	549	0.09	0.9294
Short-haul (≤100 miles)	0.03137	0.0511	180	0.61	0.5399
Large (>500 power units)	-0.01357	0.0192	1321	-0.71	0.4808
Medium (51–500 power units)	0.00339	0.0232	1083	0.15	0.8836
Small (1–50 power units)	0.06616	0.0526	356	1.26	0.2096
Dry-van	0.06616	0.0526	356	1.26	0.2096
Flat-bed	-0.00677	0.0275	490	-0.25	0.8057
Refrigerated	-0.01010	0.0346	364	-0.29	0.7705
Tanker	-0.08390	0.0636	142	-1.32	0.1894

*Statistically significant difference at .05 level.

Table 51. Analysis of poolability among industry segments: self-reported SS during restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.00812	0.0391	2418	-0.21	0.8353
Regional (101–250 miles)	-0.00953	0.0457	646	-0.21	0.8347
Short-haul (≤100 miles)	-0.02886	0.0720	239	-0.40	0.6887
Large (>500 power units)	0.00582	0.0338	1699	0.17	0.8636
Medium (51–500 power units)	-0.09747	0.0495	1325	-1.97	0.0492
Small (1–50 power units)	0.13070	0.1059	378	1.24	0.2176
Dry-van	-0.02827	0.0378	2014	-0.75	0.4550
Flat-bed	-0.05439	0.0789	610	-0.69	0.4906
Refrigerated	-0.05412	0.0585	568	-0.92	0.3555
Tanker	0.13310	0.1028	152	1.30	0.1971

*Statistically significant difference at .05 level.

Table 52. Analysis of poolability among industry segments: self-reported SS during restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.02012	0.0211	2137	0.95	0.3403
Regional (101–250 miles)	0.03115	0.0325	506	0.96	0.3382
Short-haul (≤100 miles)	0.01064	0.0561	190	0.19	0.8497
Large (>500 power units)	0.00308	0.0203	1382	0.15	0.8798
Medium (51–500 power units)	0.00011	0.0275	1150	0.00	0.9969
Small (1–50 power units)	0.13110	0.0679	345	1.93	0.0543
Dry-van	0.02765	0.0221	1741	1.25	0.2112
Flat-bed	-0.02407	0.0391	559	-0.62	0.5386
Refrigerated	0.01259	0.0397	443	0.32	0.7510
Tanker	0.03027	0.0680	120	0.45	0.6568

*Statistically significant difference at .05 level.

Table 53. Analysis of poolability among industry segments: self-reported FS during duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.00495	0.0258	2035	0.19	0.8480
Regional (101–250 miles)	0.01907	0.0422	536	0.45	0.6513
Short-haul (≤100 miles)	-0.00050	0.0551	185	-0.01	0.9928
Large (>500 power units)	-0.00804	0.0301	1370	-0.27	0.7894
Medium (51–500 power units)	0.01306	0.0324	1114	0.40	0.6870
Small (1–50 power units)	0.02366	0.0539	346	0.44	0.6608
Dry-van	-0.04719	0.0269	1713	-1.76	0.0791
Flat-bed	0.03674	0.0461	472	0.80	0.4262
Refrigerated	-0.00150	0.0486	401	-0.03	0.9755
Tanker	0.24490	0.0914	144	2.68	0.0082

*Statistically significant difference at .05 level.

Table 54. Analysis of poolability among industry segments: self-reported FS during duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.00146	0.0141	1949	0.10	0.9176
Regional (101–250 miles)	0.02828	0.0315	553	0.90	0.3695
Short-haul (≤100 miles)	0.04245	0.0469	196	0.90	0.3667
Large (>500 power units)	0.00556	0.0184	1270	0.30	0.7627
Medium (51–500 power units)	0.00163	0.0183	1040	0.09	0.9292
Small (1–50 power units)	0.03260	0.0349	337	0.94	0.3503
Dry-van	0.02066	0.0158	1614	1.31	0.1914
Flat-bed	-0.00532	0.0236	490	-0.23	0.8213
Refrigerated	-0.00693	0.0344	361	-0.20	0.8403
Tanker	-0.02919	0.0636	138	-0.46	0.6471

*Statistically significant difference at .05 level.

Table 55. Analysis of poolability among industry segments: self-reported FS during restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.04543	0.0383	3107	1.19	0.2358
Regional (101–250 miles)	0.06684	0.0606	711	1.10	0.2702
Short-haul (≤100 miles)	0.12510	0.0990	277	1.26	0.2077
Large (>500 power units)	-0.00749	0.0425	1898	-0.18	0.8602
Medium (51–500 power units)	0.12170	0.0507	1785	2.40	0.0164*
Small (1–50 power units)	0.09990	0.0822	458	1.22	0.2247
Dry-van	0.02618	0.0386	2588	0.68	0.4982
Flat-bed	0.00684	0.0718	775	0.10	0.9242
Refrigerated	0.12920	0.0808	595	1.60	0.1103
Tanker	0.20790	0.1312	148	1.58	0.1152

*Statistically significant difference at .05 level.

Table 56. Analysis of poolability among industry segments: self-reported FS during restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.02087	0.0199	2341	1.05	0.2935
Regional (101–250 miles)	-0.00824	0.0405	439	-0.20	0.8388
Short-haul (≤100 miles)	0.01402	0.0733	180	0.19	0.8485
Large (>500 power units)	-0.03611	0.0248	1382	-1.45	0.1462
Medium (51–500 power units)	0.03858	0.0265	1226	1.45	0.1461
Small (1–50 power units)	0.09836	0.0496	325	1.98	0.0482*
Dry-van	0.01936	0.0212	1757	0.91	0.3619
Flat-bed	-0.00571	0.0344	623	-0.17	0.8682
Refrigerated	-0.03837	0.0536	421	-0.72	0.4748
Tanker	0.03226	0.0866	116	0.37	0.7103

*Statistically significant difference at .05 level.

Table 57. Analysis of poolability among industry segments: self-reported KSS during duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.03169	0.0373	2125	-0.85	0.3956
Regional (101–250 miles)	0.06816	0.0564	502	1.21	0.2274
Short-haul (≤100 miles)	0.01610	0.0973	177	0.17	0.8688
Large (>500 power units)	0.03549	0.0425	1408	0.84	0.4037
Medium (51–500 power units)	-0.01197	0.0483	1143	-0.25	0.8040
Small (1–50 power units)	-0.04671	0.0804	352	-0.58	0.5616
Dry-van	Algorithm was not able to generate estimate for this cell.	.	.	.	.
Flat-bed	0.03503	0.0639	493	0.55	0.5837
Refrigerated	-0.06440	0.0752	340	-0.86	0.3923
Tanker	0.23240	0.1240	146	1.87	0.0629

*Statistically significant difference at .05 level.

Table 58. Analysis of poolability among industry segments: self-reported KSS during duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.00162	0.0203	2016	-0.08	0.9365
Regional (101–250 miles)	0.05571	0.0423	547	1.32	0.1881
Short-haul (≤100 miles)	-0.04970	0.0830	190	-0.60	0.5498
Large (>500 power units)	0.03388	0.0258	1285	1.31	0.1892
Medium (51–500 power units)	-0.02077	0.0271	1050	-0.77	0.4438
Small (1–50 power units)	0.03401	0.0519	341	0.66	0.5129
Dry-van	Algorithm was not able to generate estimate for this cell.	.	.	.	.
Flat-bed	0.04979	0.0328	512	1.52	0.1291
Refrigerated	-0.04421	0.0527	294	-0.84	0.4023
Tanker	-0.02222	0.0862	140	-0.26	0.7969

*Statistically significant difference at .05 level.

Table 59. Analysis of poolability among industry segments: self-reported KSS during restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.13840	0.0895	893	1.55	0.1223
Regional (101–250 miles)	0.06816	0.0564	502	1.21	0.2274
Short-haul (≤100 miles)	0.23920	0.1666	286	1.44	0.1523
Large (>500 power units)	0.02674	0.0669	2196	0.40	0.6892
Medium (51–500 power units)	Algorithm was not able to generate estimate for this cell.	.	.	.	.
Small (1–50 power units)	0.10550	0.1320	446	0.80	0.4246
Dry-van	0.04934	0.0603	2884	0.82	0.4134
Flat-bed	0.02974	0.1118	901	0.27	0.7903
Refrigerated	0.21120	0.1368	606	1.54	0.1233
Tanker	0.26590	0.1961	144	1.36	0.1772

*Statistically significant difference at .05 level.

Table 60. Analysis of poolability among industry segments: self-reported KSS during restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.02273	0.0311	2413	0.73	0.4643
Regional (101–250 miles)	-0.02282	0.0579	489	-0.39	0.6936
Short-haul (≤100 miles)	-0.00860	0.1217	176	-0.07	0.9438
Large (>500 power units)	-0.07489	0.0383	1495	-1.95	0.0508
Medium (51–500 power units)	Algorithm was not able to generate estimate for this cell.	.	.	.	.
Small (1–50 power units)	0.17120	0.0793	308	2.16	0.0316*
Dry-van	0.00720	0.0326	1845	0.22	0.8254
Flat-bed	0.00310	0.0528	694	0.06	0.9533
Refrigerated	-0.05444	0.0905	422	-0.60	0.5477
Tanker	0.02681	0.1289	110	0.21	0.8356

*Statistically significant difference at .05 level.

Table 61. Analysis of poolability among industry segments: self-reported mean sleep quality during duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.03914	0.0301	1940	-1.30	0.1938
Regional (101–250 miles)	-0.04922	0.0549	462	-0.90	0.3708
Short-haul (≤100 miles)	0.02723	0.1068	163	0.25	0.7991
Large (>500 power units)	-0.01687	0.0350	1155	-0.48	0.6296
Medium (51–500 power units)	-0.02969	0.0416	1072	-0.71	0.4754
Small (1–50 power units)	-0.07460	0.0666	339	-1.12	0.2633
Dry-van	-0.03745	0.0328	1516	-1.14	0.2542
Flat-bed	0.00573	0.0562	519	0.10	0.9189
Refrigerated	0.03262	0.0692	383	0.47	0.6378
Tanker	-0.19420	0.0912	143	-2.13	0.035*

*Statistically significant difference at .05 level.

Table 62. Analysis of poolability among industry segments: self-reported mean sleep quality during duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.00873	0.0167	1934	-0.52	0.6002
Regional (101–250 miles)	-0.01399	0.0409	461	-0.34	0.7324
Short-haul (≤100 miles)	-0.03188	0.0918	163	-0.35	0.7289
Large (>500 power units)	-0.00873	0.0218	1152	-0.40	0.6888
Medium (51–500 power units)	-0.00355	0.0242	1071	-0.15	0.8835
Small (1–50 power units)	-0.04165	0.0434	338	-0.96	0.3373
Dry-van	-0.00678	0.0196	1510	-0.35	0.7296
Flat-bed	0.01108	0.0278	518	0.40	0.6903
Refrigerated	-0.07426	0.0510	382	-1.46	0.1458
Tanker	-0.01129	0.0638	143	-0.18	0.8599

*Statistically significant difference at .05 level.

Table 63. Analysis of poolability among industry segments: self-reported mean sleep quality during restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.06672	0.0379	1916	-1.76	0.0784
Regional (101–250 miles)	-0.02196	0.0614	468	-0.36	0.7206
Short-haul (≤100 miles)	-0.02970	0.0939	164	-0.32	0.7523
Large (>500 power units)	-0.01318	0.0413	1146	-0.32	0.7497
Medium (51–500 power units)	-0.11880	0.0469	1063	-2.53	0.0115*
Small (1–50 power units)	-0.07418	0.0925	337	-0.80	0.4232
Dry-van	-0.06309	0.0390	1510	-1.62	0.1058
Flat-bed	-0.03028	0.0810	516	-0.37	0.7086
Refrigerated	-0.02337	0.0673	372	-0.35	0.7284
Tanker	-0.19010	0.1175	139	-1.62	0.1082

*Statistically significant difference at .05 level.

Table 64. Analysis of poolability among industry segments: self-reported mean sleep quality during restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.00614	0.0210	1909	-0.29	0.7695
Regional (101–250 miles)	0.07162	0.0456	467	1.57	0.1172
Short-haul (≤100 miles)	0.04745	0.0828	164	0.57	0.5674
Large (>500 power units)	0.04022	0.0257	1145	1.57	0.1171
Medium (51–500 power units)	0.01463	0.0277	1063	0.53	0.5970
Small (1–50 power units)	-0.12940	0.0591	335	-2.19	0.0294*
Dry-van	0.02668	0.0233	1502	1.15	0.2517
Flat-bed	-0.01432	0.0413	513	-0.35	0.7286
Refrigerated	0.01501	0.0495	378	0.30	0.7619
Tanker	-0.08635	0.0822	139	-1.05	0.2952

*Statistically significant difference at .05 level.

Table 65. Analysis of poolability among industry segments: mean work hours/day in duty period as determined through ELD data (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.03005	0.1180	2284	0.25	0.7990
Regional (101–250 miles)	0.24870	0.1710	562	1.45	0.1465
Short-haul (≤100 miles)	0.04460	0.3089	245	0.14	0.8853
Large (>500 power units)	0.22640	0.1160	1504	1.95	0.0512
Medium (51–500 power units)	0.00887	0.1637	1187	0.05	0.9568
Small (1–50 power units)	-0.12960	0.2952	393	-0.44	0.6609
Dry-van	0.09086	0.1159	1846	0.78	0.4331
Flat-bed	0.01381	0.2328	557	0.06	0.9527
Refrigerated	-0.04181	0.2526	515	-0.17	0.8686
Tanker	0.19990	0.3376	148	0.59	0.5546

*Statistically significant difference at .05 level.

Table 66. Analysis of poolability among industry segments: mean work hours/day in duty period as determined through ELD data (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.04537	0.0661	2264	-0.69	0.4928
Regional (101–250 miles)	0.04714	0.1271	555	0.37	0.7109
Short-haul (≤100 miles)	0.69610	0.2622	246	2.65	0.0085*
Large (>500 power units)	0.05376	0.0735	1499	0.73	0.4645
Medium (51–500 power units)	0.17620	0.0952	1182	1.85	0.0645
Small (1–50 power units)	-0.19820	0.1904	387	-1.04	0.2985
Dry-van	0.10810	0.0701	1833	1.54	0.1235
Flat-bed	0.02499	0.1174	547	0.21	0.8315
Refrigerated	0.12350	0.1817	524	0.68	0.4968
Tanker	-0.39260	0.2387	148	-1.64	0.1022

*Statistically significant difference at .05 level.

Table 67. Analysis of poolability among industry segments: mean driving hours/day in duty period as determined through ELD data (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.13910	0.1187	2298	1.17	0.2415
Regional (101–250 miles)	0.10630	0.1467	557	0.72	0.4692
Short-haul (≤100 miles)	0.15000	0.2446	245	0.61	0.5403
Large (>500 power units)	0.14980	0.1069	1518	1.40	0.1612
Medium (51–500 power units)	0.24010	0.1643	1167	1.46	0.1443
Small (1–50 power units)	0.00792	0.2815	398	0.03	0.9776
Dry-van	0.09266	0.1157	1862	0.80	0.4231
Flat-bed	0.11730	0.2289	555	0.51	0.6085
Refrigerated	0.17810	0.2065	514	0.86	0.3889
Tanker	0.58110	0.3638	148	1.60	0.1123

*Statistically significant difference at .05 level.

Table 68. Analysis of poolability among industry segments: mean driving hours/day in duty period as determined through ELD data (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.05508	0.0666	2278	-0.83	0.4080
Regional (101–250 miles)	0.03089	0.1089	554	0.28	0.7767
Short-haul (≤100 miles)	0.32620	0.2076	245	1.57	0.1174
Large (>500 power units)	0.01805	0.0677	1511	0.27	0.7898
Medium (51–500 power units)	0.06397	0.0955	1166	0.67	0.5031
Small (1–50 power units)	-0.32480	0.1817	393	-1.79	0.0747
Dry-van	0.01525	0.0701	1845	0.22	0.8277
Flat-bed	0.14740	0.1153	547	1.28	0.2017
Refrigerated	-0.17940	0.1488	519	-1.21	0.2287
Tanker	-0.34890	0.2572	148	-1.36	0.1770

*Statistically significant difference at .05 level.

Table 69. Analysis of poolability among industry segments: length of restart period (hours) as determined through ELD data (1-night restart – 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-10.9790	3.5487	2390	-3.09	0.0020*
Regional (101–250 miles)	-18.3282	3.0367	571	-6.04	<.0001*
Short-haul (≤100 miles)	-23.9920	4.2308	249	-5.67	<.0001*
Large (>500 power units)	-15.6274	3.4143	1576	-4.58	<.0001*
Medium (51–500 power units)	-12.6250	3.4745	1196	-3.63	0.0003*
Small (1–50 power units)	-6.8325	8.9642	404	-0.76	0.4464
Dry-van	-13.7980	2.9434	1891	-4.69	<.0001*
Flat-bed	-14.0084	6.5236	555	-2.15	0.0322*
Refrigerated	-13.6418	7.1734	536	-1.90	0.0577
Tanker	-4.2213	8.9840	150	-0.47	0.6391

*Statistically significant difference at .05 level.

Table 70. Analysis of poolability among industry segments: length of restart period (hours) as determined through ELD data (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.5165	2.0064	2368	0.26	0.7969
Regional (101–250 miles)	0.6642	2.2815	564	0.29	0.7711
Short-haul (≤100 miles)	9.5274	3.5863	247	2.66	0.0084*
Large (>500 power units)	0.5930	2.1856	1584	0.27	0.7862
Medium (51–500 power units)	0.5344	2.0342	1211	0.26	0.7928
Small (1–50 power units)	3.6451	5.8115	395	0.63	0.5309
Dry-van	0.2480	1.8101	1920	0.14	0.8910
Flat-bed	7.7887	3.3364	555	2.33	0.0199*
Refrigerated	-2.7985	5.0958	548	-0.55	0.5831
Tanker	3.2391	6.3231	150	0.51	0.6092

*Statistically significant difference at .05 level.

Table 71. Analysis of poolability among industry segments: length of duty period (hours) as determined through ELD data (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-8.0724	5.3910	2298	-1.50	0.1344
Regional (101–250 miles)	-0.6984	4.5847	572	-0.15	0.8790
Short-haul (≤100 miles)	-3.9710	5.8805	248	-0.68	0.5001
Large (>500 power units)	-8.0483	5.4292	1526	-1.48	0.1384
Medium (51–500 power units)	-0.4042	5.4203	1194	-0.07	0.9406
Small (1–50 power units)	-4.1426	12.2983	397	-0.34	0.7364
Dry-van	-6.2399	4.6761	1861	-1.33	0.1822
Flat-bed	4.1499	10.2754	560	0.40	0.6865
Refrigerated	-6.0577	9.7566	515	-0.62	0.5350
Tanker	11.3885	14.9937	149	0.76	0.4487

*Statistically significant difference at .05 level.

Table 72. Analysis of poolability among industry segments: length of duty period (hours) as determined through ELD data (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.2952	3.0246	2268	0.10	0.9223
Regional (101–250 miles)	3.0173	3.4383	562	0.88	0.3806
Short-haul (≤100 miles)	-9.0752	4.9815	247	-1.82	0.0697
Large (>500 power units)	-0.4525	3.4424	1514	-0.13	0.8954
Medium (51–500 power units)	-0.0983	3.1549	1185	-0.03	0.9751
Small (1–50 power units)	-3.8138	7.9610	388	-0.48	0.6322
Dry-van	-3.6059	2.8338	1838	-1.27	0.2034
Flat-bed	7.0444	5.1931	549	1.36	0.1755
Refrigerated	0.2870	7.0043	528	0.04	0.9673
Tanker	3.5505	10.5997	149	0.33	0.7381

*Statistically significant difference at .05 level.

Table 73. Analysis of poolability among industry segments: adjudicated sleep per 24 hours of duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.0457	0.0800	1726	-0.57	0.5679
Regional (101–250 miles)	-0.1029	0.0998	450	-1.03	0.3030
Short-haul (≤100 miles)	-0.2001	0.1981	172	-1.01	0.3140
Large (>500 power units)	-0.1105	0.0803	1077	-1.38	0.1694
Medium (51–500 power units)	-0.1200	0.1051	954	-1.14	0.2538
Small (1–50 power units)	-0.0602	0.1753	298	-0.34	0.7317
Dry-van	-0.0374	0.0775	1452	-0.48	0.6290
Flat-bed	-0.0348	0.1486	437	-0.23	0.8149
Refrigerated	-0.3965	0.1825	306	-2.17	0.0306*
Tanker	-0.0519	0.1883	124	-0.28	0.7832

*Statistically significant difference at .05 level.

Table 74. Analysis of poolability among industry segments: adjudicated sleep per 24 hours of duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.0477	0.0445	1712	1.07	0.2839
Regional (101–250 miles)	-0.0336	0.0775	446	-0.43	0.6649
Short-haul (≤100 miles)	-0.2066	0.1695	170	-1.22	0.2245
Large (>500 power units)	-0.0022	0.0518	1075	-0.04	0.8954
Medium (51–500 power units)	-0.0341	0.0594	953	-0.57	0.5662
Small (1–50 power units)	0.0018	0.1177	297	0.02	0.9876
Dry-van	-0.0818	0.0471	1443	-1.74	0.0824
Flat-bed	0.2176	0.0773	434	2.82	0.0051*
Refrigerated	-0.1287	0.1264	314	-1.02	0.3093
Tanker	0.0959	0.1357	124	0.71	0.4812

*Statistically significant difference at .05 level.

Table 75. Analysis of poolability among industry segments: adjudicated sleep per 24 hours of restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.2919	0.1606	1341	-1.82	0.0694
Regional (101–250 miles)	0.6862	0.1966	318	3.49	0.0006*
Short-haul (≤100 miles)	0.3247	0.2672	158	1.22	0.2261
Large (>500 power units)	0.5133	0.1633	791	3.14	0.0017*
Medium (51–500 power units)	-0.4757	0.1966	758	-2.42	0.0158*
Small (1–50 power units)	-0.8713	0.3015	260	-2.89	0.0042*
Dry-van	0.2050	0.1496	1086	1.37	0.1708
Flat-bed	-0.4696	0.3572	360	-1.31	0.1894
Refrigerated	0.0117	0.2665	253	0.04	0.9649
Tanker	-0.1642	0.3455	102	-0.48	0.6357

*Statistically significant difference at .05 level.

Table 76. Analysis of poolability among industry segments: adjudicated sleep per 24 hours of restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	-0.1376	0.0899	1334	-1.53	0.1263
Regional (101–250 miles)	-0.1687	0.1575	311	-1.07	0.2849
Short-haul (≤100 miles)	-0.4536	0.2430	156	-1.87	0.0638
Large (>500 power units)	-0.1370	0.1068	791	-1.28	0.1999
Medium (51–500 power units)	-0.0734	0.1089	759	-0.67	0.5008
Small (1–50 power units)	-0.0862	0.2202	256	-0.39	0.6956
Dry-van	-0.2217	0.0927	1075	-2.39	0.0169*
Flat-bed	-0.2979	0.1698	356	-1.75	0.0802
Refrigerated	0.3793	0.2180	260	1.74	0.0831
Tanker	-0.0838	0.2484	102	-0.34	0.7366

*Statistically significant difference at .05 level.

Table 77. Analysis of poolability among industry segments: PVT-B mean reciprocal response time in the duty period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.0119	0.0192	2041	0.62	0.5363
Regional (101–250 miles)	-0.0585	0.0345	533	-1.69	0.0907
Short-haul (≤100 miles)	0.0238	0.0446	210	0.53	0.5936
Large (>500 power units)	-0.0296	0.0237	1332	-1.25	0.2118
Medium (51–500 power units)	0.0247	0.0255	1128	0.97	0.3339
Small (1–50 power units)	0.0281	0.0301	350	0.93	0.3516
Dry-van	-0.0175	0.0221	1712	-0.79	0.4288
Flat-bed	0.0195	0.0358	514	0.55	0.5859
Refrigerated	0.0281	0.0321	389	0.87	0.3826
Tanker	0.0117	0.0373	141	0.31	0.7539

*Statistically significant difference at .05 level.

Table 78. Analysis of poolability among industry segments: PVT-B mean reciprocal response time in the duty period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.0148	0.0106	1996	1.40	0.1627
Regional (101–250 miles)	0.0084	0.0258	526	0.33	0.7448
Short-haul (≤100 miles)	0.0718	0.0376	212	1.91	0.0573
Large (>500 power units)	0.0187	0.0148	1284	1.27	0.2061
Medium (51–500 power units)	0.0326	0.0146	1103	2.23	0.0261*
Small (1–50 power units)	-0.0258	0.0196	345	-1.32	0.1870
Dry-van	0.0243	0.0132	1669	1.85	0.0650
Flat-bed	0.0147	0.0181	523	0.81	0.4176
Refrigerated	0.0231	0.0232	377	1.00	0.3194
Tanker	-0.0486	0.0260	136	-1.87	0.0636

*Statistically significant difference at .05 level.

Table 79. Analysis of poolability among industry segments: PVT-B mean reciprocal response time in the restart period (1-night restart minus 2-night restart).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.0117	0.0231	2331	0.50	0.6143
Regional (101–250 miles)	-0.0078	0.0404	570	-0.19	0.8473
Short-haul (≤100 miles)	0.0297	0.0455	225	0.65	0.5150
Large (>500 power units)	0.0164	0.0272	1492	0.60	0.5453
Medium (51–500 power units)	-0.0081	0.0299	1260	-0.27	0.7855
Small (1–50 power units)	0.0356	0.0437	380	0.81	0.4157
Dry-van	-0.0059	0.0251	1939	-0.24	0.8126
Flat-bed	0.0945	0.0477	573	1.98	0.0480*
Refrigerated	0.0330	0.0360	452	0.92	0.3601
Tanker	-0.0178	0.0614	142	-0.29	0.7721

*Statistically significant difference at .05 level.

Table 80. Analysis of poolability among industry segments: PVT-B mean reciprocal response time in the restart period (restarts taken in less than 168 hours minus restarts taken in at least 168 hours).

Industry Segment	Estimate	Standard Error	DF	T-value	P-value
Long-haul (>250 miles)	0.0296	0.0125	2080	2.37	0.0180*
Regional (101–250 miles)	0.0115	0.0295	497	0.39	0.6962
Short-haul (≤100 miles)	0.0108	0.0360	187	0.30	0.7654
Large (>500 power units)	0.0297	0.0167	1326	1.78	0.0755
Medium (51–500 power units)	0.0322	0.0166	1093	1.94	0.0528
Small (1–50 power units)	-0.0051	0.0277	336	-0.18	0.8554
Dry-van	0.0309	0.0147	1702	2.10	0.0354*
Flat-bed	0.0366	0.0237	527	1.55	0.1220
Refrigerated	0.0125	0.0249	383	0.50	0.6151
Tanker	-0.0240	0.0418	125	-0.57	0.5669

*Statistically significant difference at .05 level.

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