Study of the Impact of a Telematics System on Safe and Fuel-efficient Driving in Trucks

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

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FOREWORD

Phase I of the Motor Carrier Efficiency Study (MCES) identified a broad array of technology applications that have the potential to leverage advancements in wireless communications. With the commercial rollout of fourth-generation (commonly called 4G) wireless telecommunications systems, creative developers have greater opportunity to develop useful tools to exploit high-speed, data-rich communications networks. The convergence of advanced wireless capabilities and increasingly sophisticated onboard computing capabilities presents a timely opportunity to explore new ways to improve commercial motor vehicle (CMV) driver performance, and simultaneously enhance CMV safety and fuel efficiency.

This report is an evaluation of the use of telematics systems focusing on safe and fuel-efficient driving. Telematics is technology that combines telecommunications (i.e., the transmission of data from on-board vehicle sensors) and global positioning system (GPS) information (i.e., time and location) to monitor driver and vehicle performance.

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16. Abstract

A telematics system has been successfully demonstrated to be useful for improving motor carrier efficiency. In this particular field study, the research team demonstrated that telematics can be used to monitor and improve safe driving behavior as well as to monitor and improve fuel economy in trucks.

Telematics were used to monitor various driver performance parameters: unsafe events (sudden accelerations and hard braking expressed as "yellow" and "red" events, depending on severity), speeding, engine revolutions per minute (RPM), and fuel economy. As the result of monitoring unsafe events and of driver intervention (i.e., providing of information, feedback, training, and/or an incentive to modify driver behavior), drivers of sleeper cabs showed a 55-percent reduction in less severe (yellow) unsafe events and a 60-percent reduction in more severe (red) unsafe events. The following appear to be the indirect effects of the intervention process that focused on reducing yellow and red events: drivers of sleeper cabs (long-haul drivers) showed a 42-percent decrease in percent of miles driving at > 65 miles per hour (mi/h), and drivers of day cabs showed a 33-percent decrease in percent of miles driving at > 65 mi/h (i.e., speeding). Drivers of sleeper cabs showed a 48-percent decline in percent of miles driven at > 1,500 RPM, and drivers of day cabs showed a 27-percent increase in percent of miles driven at > 1,500 RPM. As all of the above trends were taking place, fuel economy improved by 5.4 percent for drivers of sleeper cabs and by 9.3 percent for drivers of day cabs.

The data appear to suggest that fuel economy correlates to safe driving. Because safe driving can be said to conserve fuel, and conserving fuel reduces emissions, safe driving can also be said to reduce emissions.

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SI* (MODERN METRIC) CONVERSION FACTORS

Table of 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	1000 L 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 (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in 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

Table of 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 (2000 lb)	T
		TEMPERATURE	Temperature is in 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 & 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 ABBREVIATIONS AND ACRONYMS

4G	fourth-generation
CDL	commercial driver's license
CMV	commercial motor vehicle
CO_2	carbon dioxide
ECU	engine control unit
FMCSA	Federal Motor Carrier Safety Administration
MCES	Motor Carrier Efficiency Study
GPS	global positioning system
ITS	intelligent transportation systems
mi/gal	miles per gallon
mi/h	miles per hour
NOx	nitrogen oxides
RFID	radio frequency identification devices
RPM	revolutions per minute
VMT	vehicle miles traveled

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EXECUTIVE SUMMARY

BACKGROUND

To gain an advantage in the transportation industry, today's transportation and logistics companies increasingly rely on modern technologies and in-vehicle tools to optimize their truck fleet operations. These technologies are sometimes combined with specialized intervention that provides drivers feedback, training, and/or incentive programs that can improve truck fleet management and reinforce safe and fuel-efficient driving behavior. The approach for improvement combines in-vehicle technology with integrated Web-based applications that continuously monitor and rate driving behavior and provide real-time feedback to drivers. The programs also provide positive motivation and constant reinforcement to drivers to change their behavior behind the wheel and to sustain the improved behavior. From this approach, fleet managers and risk and safety professionals gain insight into driving behavior and the necessary tools to help drivers achieve specific safety and fuel-efficiency goals.

Driver behavior is by far the largest single contributor to improving fuel efficiency. There can be as much as a 35-percent difference in fuel consumption between a good driver and a poor driver.[(1)] Therefore, improving fuel efficiency by encouraging improved driving habits is among the most promising measures to reduce fleet operation costs. Because fuel costs account for a significant portion of overall motor carrier operating costs, technologies that reduce fuel consumption and encourage responsible driving behavior have tremendous potential.

PROCESS

This study represents a comprehensive initial examination of the interrelation between safety and fuel consumption of heavy-duty trucks before and after driver intervention using telematics. Telematics is technology that combines telecommunications (i.e., the transmission of data from on-board vehicle sensors) and global positioning system (GPS) information (i.e., time and location) to monitor driver and vehicle performance. Researchers conducted a 10-month field evaluation that included installing telematics technologies in Class 8 trucks (defined as trucks having a gross vehicle weight rating of 33,001 pounds or more) in combination with staged driver intervention. The steps in the study process were:

1. Vehicle specification.
2. Recruitment of fleet.
3. Wireless technology system selection and data requirements.
4. Installation of technology.
5. Data collection.
6. Evaluation and statistical analyses.

The truck drivers naturally fell into two distinct groups, namely, drivers of day cabs and drivers of sleeper cabs; thus, the data was collected separately for day cabs and for sleeper cabs. The two groups were subdivided into a pilot group and a control group, resulting in four total combinations: pilot day cabs, control day cabs, pilot sleeper cabs, and control sleeper cabs. While all four groups were monitored for driver performance, the driver intervention process (i.e., feedback, coaching, and rewards) was applied only to the pilot groups.

PURPOSE

This study focused on examining the relationship between safe driving and fuel consumption in heavy-duty truck operations. Commercial motor vehicles (CMVs) are vital in moving the Nation's freight and they make up about 4 percent of the vehicles on the road, but they account for more than 20 percent of all fuel consumed in the United States. The subject of this study, Class 8 trucks,(2) generally have the highest annual fuel use, and their energy demand accounts for approximately 65 percent of the total fuel consumed by all truck classes. Fuel is the number one non-labor operating expense for truck fleets, and the estimated annual fuel cost of Class 8 trucks can range from 28 to 38 percent of the operating costs.(3) Thus, reductions in fuel consumption will improve fleet profitability. The question is: "Can improved fuel economy be associated with safer driving?"

STUDY FINDINGS

Key findings resulting from monitoring driving performance with a telematics system and providing feedback to the driver as well as coaching and incentives for improved driving performance are as follows:

- Unsafe events defined as sudden acceleration, hard braking, and sudden lane changes decreased by almost 50 percent across both day cab and sleeper cab groups.
- Distances driven at speeds more than 65 miles per hour (mi/h) decreased by more than 33 percent for day cabs and 42 percent for the sleeper cab groups.
- Distances driven at more than 1,500 revolutions per minute (RPM) increased 27 percent for day cab groups and decreased 48 percent for sleeper cab groups.
- Fuel economy improved by 5 and 9 percent, respectively, for sleeper cab and day cab groups.

Overall, the study appears to show a correlation between fuel economy and safe driving—trends on fuel economy exhibited a rise as trends on unsafe events exhibited a decline, with the data on both parameters originating from the same set of drivers. This means that safer driving may be said to conserve fuel. Since safe driving is said to conserve fuel, and conserving fuel reduces emissions, then safe driving can also be said to reduce emissions.

RECOMMENDATIONS

Key recommendations include:

- Vendors should be encouraged to develop and market telematics technologies that monitor key fuel and safety performance variables. Telematics systems must be able to generate daily updates on driver performance (as opposed to vehicle performance), as well as summary statistics on the fleet customized to the needs of respective audiences (i.e., fleet managers, drivers, and executives). These data must be made available beyond the vendor's Web site and emailed to the client's place of operations. The key to a successful safety/fuel efficiency culture is easy access to data that are available immediately for use and customized to the needs of the respective audiences.
- The importance of establishing a new safety/fuel efficiency culture should be recognized among truck fleets. Fleet managers must be exposed to training prior to communicating feedback or providing coaching to drivers on safety and fuel economy.
- Documentation should be developed that focuses on the new safety/fuel efficiency culture that specifically targets the needs of various stakeholders—fleet executives, fleet managers, and drivers.
- Federal agencies should provide guidance and resources to advance the safety/fuel efficiency culture. The motor carrier fleets must champion this new safety/fuel efficiency culture program for the trucking industry.
- Additional research is recommended to further investigate the study findings over the longer period (36–60 months). The rationale is that a longer period allows for collection of crash data, which are more definitive measures of safe driving. Because this study was limited in scope, the study team was not able to collect sufficient crash data, and instead, examined proxies for safety, such as unsafe events defined as harsh accelerations, hard braking, and sudden lane changes.
- It is recommended that a similar study be undertaken with motorcoach drivers.

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1. INTRODUCTION

1.1 REPORT PURPOSE

This report examines the relationship between safe driving and fuel consumption of heavy-duty trucks. The study is important because trucks deliver 69 percent[(2)] of the freight tonnage that this Nation consumes; thus, logistics planning and fleet management efficiency are crucial to today's businesses and industries. Even as the Internet offers alternatives to many traditional supply chain functions, such as sales and retail services, the one aspect not eliminated is the need to transport and deliver goods between businesses and consumers and ensure the timely delivery of supplies and materials that keep the supply chain operating efficiently.

Heavy-duty trucks are vital in moving the Nation's freight—they make up about 4 percent of the vehicles on the road, but they account for more than 20 percent of all fuel consumed in the United States.[(2)] Class 8 trucks (defined as trucks having a gross vehicle weight rating of 33,001 pounds or more), the subject of this study, generally travel between 150,000 and 200,000 miles per year, and their energy demand accounts for approximately 65 percent of the total fuel consumed by all truck classes. Fuel is the number one non-labor operating expense for truck fleets. The estimated annual fuel cost of Class 8 trucks is $80,000–$125,000, which ranges from 28 to 38 percent of the operating cost.[(3)] As truck fleets operate on very slim profit margins of 1–5 percent, a 5-percent increase in fuel economy translates to a profit margin increase of 30 percent. Thus, improving fuel economy can dramatically improve the survival of a truck fleet in today's tough business climate.

Estimates are that U.S. heavy-truck fleet fuel consumption will increase by more than 20 percent by 2020, which implies that the impact on operating costs as well as on the economy and the environment will be even more important in the future.[(2)] Further, more than 9 million people are involved in trucking-related jobs, and many drivers are also independent owners. It is also estimated that 50 percent of motor carriers operate one truck and 95 percent of truck fleets operate fewer than 20 trucks.[(4)] Any reduction in fuel consumption is crucial to the Nation's energy security as well as fleet sustainability.

Driver behavior is by far the largest single contributor to improving fuel economy. There can be as much as a 35-percent difference in fuel consumption between a good driver and a poor driver.[(1)] Speeding, inappropriate gear selection, aggressive accelerator and brake pedal use, and truck idling all contribute to inefficient fuel consumption.

There is a potential to enhance safety by reducing overall speed and the associated benefits, such as reduced crash rate and crash severity. In fact, there is a well-established relationship between speed and crash outcome severity. A 5-percent decrease in average speeds leads to approximately a 10-percent decrease in injury crashes and a 20-percent decrease in fatal crashes.[(5)] In addition to increased safety, reducing speed also reduces fuel consumption. Truck fuel consumption increases significantly as speed rises above 55 miles per hour (mi/h), and 50 percent of the mileage of all combination trucks occurs at speeds above 55 mi/h. With interstate speed limits generally set at 65–75 mi/h, reducing long-haul truck freeway driving to 60 mi/h or less could have a major impact on reducing fuel consumption.[(3)] Generally, the rule of thumb is that for every mi/h increase above 50 mi/h, fuel consumption increases by 0.1 miles per gallon (mi/gal).[6] Team discussions with fleet managers and drivers across the Nation cite that the most common reason for speeding is the pressure to meet deadlines. Numerous studies, including the literature review for this report, show that the myth that speeding and driving aggressively substantially reduce travel time is misleading. In fact, speeding and aggressive driving may reduce travel time by less than 8 seconds per mile when traveling in free-flow conditions, but this is often offset by road geometrics, congestion, and other traffic-related conditions, any or all of which demand slower speeds.[7] As already stated, a consequence of lower speeds is reduced crash severity. Fleet managers can have a major influence on driver behavior, which potentially can affect how the driver operates a vehicle on the roadway. A simple observational note from a fleet manager to a driver compared to a more formal approach through driver retraining can have significant benefits on overall driver performance. In March of 2010, in a book entitled, “Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles,” the National Academy of Sciences recommended that a curriculum and process for certifying fuel-saving driving techniques be part of obtaining a commercial driver’s license (CDL).[8]

Improved fuel-efficient driving habits, such as not speeding and not driving aggressively, are among the most promising measures to reduce fleet operation costs. Because fuel costs make up a significant portion of overall motor carrier operating costs, technologies that reduce fuel consumption and encourage responsible driving techniques have tremendous potential. In an industry where operating costs consume a substantial portion of every dollar earned, even a marginal gain in fuel economy can have a significant economic effect.

While the subject of this research is to monitor and observe driving behavior and its impacts on fuel consumption, other benefits such as reduction in greenhouse gases—carbon dioxide (CO_2) and nitrogen oxides (NOx)—cannot be overlooked. For example, the Environmental Protection Agency (EPA) estimates that every gallon of fuel saved avoids approximately 22.2 pounds of CO_2 emissions. This translates to eliminating approximately 10–15 tons of CO_2 per truck per year. While there is a clear relationship between fuel consumption and emissions avoided, the relationship between fuel consumption and safety is largely absent from the research literature.

To gain an advantage in the transportation industry, today’s transportation and logistics companies increasingly rely on telematics to track truck locations and therefore optimize truck fleet dispatching. Telematics is technology that combines telecommunications (i.e., the transmission of data from on-board vehicle sensors) and global positioning system (GPS) information (i.e., time and location) to monitor driver and vehicle performance. Several telematics systems are available to help today’s owners, operators, and logistics professionals improve their fleet operations.

These telematics systems are sometimes combined with specialized driver intervention programs (offered by some stakeholders in the fleet industry) that enable truck fleets to monitor, improve, and sustain safe and fuel-efficient driving behavior.[9,10, 11,12] Driver intervention is the providing of information, feedback, training, and/or an incentive to a driver to modify his behavior. The telematics systems combine in-vehicle technology with integrated Web-based applications that continuously monitor and rate driving behavior and provide real-time feedback to drivers. A driver intervention process can provide positive motivation to drivers to change their behavior behind the wheel, and constant reinforcement encourages them to maintain improved behavior. Although fleet managers and risk and safety professionals gain insight into driving behavior and have the necessary tools to help drivers achieve specific safety and fuel economy goals, it is estimated that fewer than 20 percent of all motor carriers have adopted any form of telematics systems.[11,13] Key reasons for fleets not adopting wireless solutions include reluctance to change business practices,[14] lack of skilled personnel to realize the benefits of telematics, low awareness of telematics, high up-front cost, and driver resistance to being monitored.

Existing telematics systems provide a range of metrics including speeding, excessive RPM, hard braking and sudden acceleration, and fuel consumption. Some telematics systems have algorithms that incorporate many of these metrics to generate a safety and/or eco-driving score. The scores may be used by fleet managers as a potential coaching tool to improve driver performance. These systems can be expensive; however, it is estimated that the average payoff period (capital cost of installation) is approximately 10–12 months.[15]

This report presents the findings of a demonstration of the use of fuel-monitoring and operations management telematics system to improve motor carrier efficiency.

1.1.1 Structure of This Report

The study documented by this report was conducted between June 2010 and December 2011. The structure of this report reflects in part the timeline of activities and findings as follows:

- This introduction provides the reader with the relevant project background and context for the project.
- Section 2 provides information on the methodology used by the research team from recruitment of a motor carrier fleet to the evaluation process deployed within the study.
- Section 3 provides information on the study hypotheses.
- Section 4 delivers the project findings. The findings are derived from the analysis and interpretation of the data provided by the telematics systems. The data collection was limited in duration by the scope of the study.
- Section 5 provides the conclusions of the study project and recommendations for future work relating to telematics systems.

1.1.2 Background

Electronic roadside screening and weigh-station-bypass initiatives have reduced costs for carriers, as have wireless radio-frequency identification devices (RFID) at international border crossings, satellite-based fleet management and communications systems, and simple cell phone-based applications. For a portion of the trucking industry—especially the larger common carriers and private fleets—these technologies have helped streamline operations and achieve higher productivity. Although per-trip gains remain modest, the volume of freight transported allows carriers to realize the benefits of economies of scale. As a result, advanced wireless technologies have become a way of life for these carriers and their supply chain partners.

Fuel economy is another area that offers significant opportunity for improvement. Because fuel costs account for a significant portion of overall motor carrier operating costs, technologies that reduce fuel consumption and encourage more responsible driving techniques offer tremendous potential. In an industry where operating costs consume approximately 96 cents of every dollar earned, even a marginal gain in fuel economy can have a significant effect.[(2)]

1.1.3 Objectives

The project objectives are as follows:

- Review the literature on the current state of fuel monitoring and operations management systems. Section 1.2 highlights the key findings of the literature review.
- Conduct a field demonstration of one or more commercially available fuel-monitoring and operations management telematics systems.
- Evaluate driver safety benefits and fuel economy benefits resulting from use of a telematics system by a motor carrier.

1.2 LITERATURE REVIEW SUMMARY

1.2.1 Summary

The Motor Carrier Efficiency Study (MCES) identified a broad array of technology applications that leverage advancements in wireless communications. With the commercial rollout of fourth-generation (4G) wireless telecommunications systems, creative developers had a greater opportunity to provide useful telematics systems to exploit high-speed, data-rich communications networks. The convergence of advanced wireless capabilities and increasingly sophisticated onboard computing capabilities presents a timely opportunity to explore new ways to improve commercial motor vehicle (CMV) driver performance—and simultaneously enhance CMV safety and increase fuel economy.

In recent decades, the trucking industry has benefited from many well-documented technical and physical innovations related to fuel economy and monitoring/management telematics systems. However, there have been relatively few documented examples of practices that encourage changes in driver behavior as a result of these innovations. An example of a driver behavior that is in need of change is the common practice of idling. The control of idling, which also reduces fuel costs for the industry, offers a substantial environmental benefit to society.

1.2.2 Observations and Implications

The research team reviewed a considerable library of documents regarding truck-based fuel monitoring and operation management systems. Each document offered useful information, and some provided valuable insights applicable later in the study. The objective of this review was to identify trends and data that would help to shape the team's analysis during the study period.

Specifically, the documents revealed useful data regarding the effects of various driver behaviors on fuel economy, such as gear shifting patterns, sudden acceleration, hard braking, and speeding—all characteristics that can be monitored by current off-the-shelf telematics systems.

The documents also referenced various specific vehicle monitoring and reporting systems, including results from studies commissioned by telematics systems manufacturers.

Finally, the research team obtained valuable information regarding some practices that carriers use to compare driver performance against other drivers and company benchmarks to educate drivers about the effects of behavior on fuel economy and to devise programs to reward improved fuel efficient driving. The series of "Freight Best Practice" documents produced in the United Kingdom were particularly useful and are applicable in developing model program elements and a test methodology to be employed in later project tasks.

1.2.3 Key Literature Findings

Common themes that resonate throughout the literature review with potential to improve driver performance are as follows:

- Use existing and emerging technologies to monitor key driving performance parameters, such as speed, RPM, unsafe events (e.g., sudden acceleration and hard braking), and fuel economy—all of which can be used with the driver intervention process to modify driving behavior to achieve lower operating cost and increase fleet profitability. The pay-off period following installation of a telematics system is relatively short, estimated at 10–12 months.
- Increase fleet manager awareness and training regarding the interrelationship of simple fuel-saving techniques, unsafe events, and other relevant driver performance parameters.
- Provide training and retraining programs for drivers.
- Provide a sound vehicle maintenance program.
- Develop and instill a culture where safety is the number one priority.
- Conduct fuel economy audits—these audits provide guidance for implementing fuel-saving measures. Note that improved fuel economy reduces emission production.

The research team found no significant past research that addressed the relationship between safe driving and fuel economy.

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2. METHODOLOGY

2.1 FIELD STUDY

The five overall phases of the field study are as follows:

- **Recruitment**. The research team initiated an effort to recruit motor carrier fleets to participate in the field study. The team drew upon its own resources, the Federal Motor Carrier Safety Administration (FMCSA), motor carrier groups in Maryland and Virginia, trade journal publications, motor carrier databases, and to the extent practical, system vendors, in order to seek key motor carrier representatives to solicit their participation in the field study.
- **Implementation**. After identifying a willing motor carrier participant, team members coordinated the logistics associated with installing the required hardware and software telematics components, or in the event a telematics system was already installed, team members negotiated the terms for data sharing.
- **Validation Testing**. When implementation was completed, the team worked with the motor carrier and telematics system vendors to ensure that all systems functioned as intended prior to live operations in the field study.
- **Live Operations**. The field study began once the vendors, carrier, and the research team were satisfied that the telematics systems were fully operational. The team gathered data throughout the live operations period (approximately 10 months) and recorded it in a manner consistent with the requirements identified in the evaluation and test plans.
- **System Disposition**. At the completion of live operations, the research team discussed plans for vendor-coordinated uninstallation of the telematics system.

2.1.1 Fleet Recruitment

During the recruitment process, the research team used the following three methods to recruit fleet participation:

- Short advertisements in motor carrier-related professional magazines and related Web sites.
- Direct contact with motor carrier fleet managers.
- Contact through motor carrier-related organizations, such as the American Trucking Associations (Maryland Trucking Association and Virginia Trucking Association).

The team received mixed responses from the companies contacted. Some motor carriers expressed willingness to work with the research team, while others wanted no involvement with federally-funded studies or other research that would collect data on their fleet activities. Finally, the team selected one motor carrier willing to participate in the field study. The primary reason for selecting this carrier was that its management was very interested in improving vehicle safety and reducing fuel costs. Further, the carrier agreed to allow the research team to equip 46 new tractors with telematics systems prior to delivery.

2.1.2 Vehicle Specification

The candidate vehicles for this study focused on the heavy-duty trucks that consume the most fuel, and thus, have the potential to realize the greatest savings. The team selected Class 8 trucks as the test vehicles, and the team took care to ensure vehicle consistency—considerations taken into account during fleet recruitment.

In early discussions with fleet managers, the team decided to separate the long-haul vehicles (sleeper cabs) from the more traditional day cabs for purposes of this study. Drivers of sleeper cabs generally operate across State lines and may not return to their base of operations for almost a week. On the other hand, day cabs typically return to their base of operations on a daily basis. Sleeper cab drivers, to some extent, consider the trucks as their own and generally become attached to their vehicles. On the other hand, the day cabs rotate among the fleet drivers, and so, there is no such attachment. Multiple-driver shifts are common with day cab operations. This was an important consideration because driver behavior, vehicle operations, environment, and vehicle configuration would differ for each vehicle group.

In the fleet selected for this field study, 46 new Class 8 tractors (24 day cabs and 22 sleeper cabs) were deployed. The two vehicle groups were identical in all respects—same manufacturer, power train, and cab (except for the sleeper berth). Thus, the team was able to control for or avoid varying features, such as aerodynamics and vehicle age. Further, the ability to instrument the trucks with telematics equipment at the dealership minimized the information passed on to the drivers that could potentially influence the baseline period.

2.1.3 Wireless Telematics System Selection

Because the 46 new Class 8 tractors came from the manufacturer with an existing telematics system for monitoring fuel consumption, the research team decided to rely on that telematics system for that particular data.

However, the fuel monitoring telematics system does not monitor safety. In fact, telematics systems do not monitor safety, per se. The definitive measures of safety are numbers of fatalities, crashes, injuries, and costs of property damage normalized over some unit (such as commercial vehicle miles traveled [VMT]). Instead, telematics systems use proxies for safety, such as hard braking, harsh acceleration, or sudden lane changes. Accelerometers can be used to measure these proxies, as was done in this study. Many telematics systems also monitor speed. However, whether a vehicle is operating at a safe speed cannot be determined without additional information, such as the speed limit and road conditions, which may not be available to the telematics systems.

In order to find a suitable telematics systems to monitor these safety proxies, the research team examined more than 20 wireless telematics system vendors via telephone interviews, in-person discussions, or through Web demonstrations of the technologies. The interviews and discussions covered capabilities, data presentation, types of feedback, costs, and after-sales service. The team then selected an in-vehicle unit with which to collect the data needed to measure these safety proxies. These technologies were internal and could be mounted within the dashboard, and therefore, would not be visible to the driver.

2.1.4 Data Requirements

The team used the safety monitoring system to collect data in the form of unsafe events—"green," "yellow," and "red." An unsafe event was categorized by color and defined as follows:

- Steady green = no sudden acceleration or no harsh deceleration event.
- Blinking green = speed > 65 mi/h.
- Yellow = moderately severe acceleration or deceleration event.
- Red = very unsafe or dangerous acceleration or deceleration event.

A harsh acceleration can include a sudden lane change or cornering. A harsh deceleration is hard braking and can take place with or without turning and with or without changing lanes. Acceleration is measured parallel or lateral to vehicle travel in feet per second squared (ft/s^2). An in-cab unit installed prior to Stage 3 displayed green (steady or blinking) and yellow and red events in the vehicle (see Section 2.1.5). The driving performance actions monitored included:

- Acceleration.
- Braking.
- Cornering.
- Lane handling.

Every trip begins with a solid green light. As the driver performs high-risk driving maneuvers, the feedback lights flash to indicate the level of risky driving and also to remind the driver to drive more safely. Speeding (e.g., driving > 65 mi/h) as determined by using the safety-monitoring system's GPS (which is not compared with and is independent of the fuel-monitoring system and engine control unit [ECU] data), would cause the green light to blink. A moderate-risk maneuver generates a flashing yellow light and a severe risk maneuver generates a red flashing light. The level of risk for different maneuver types (e.g., accelerating while in a turn) is evaluated by comparing the accelerations (gravitational forces) acting on the vehicle during the maneuver, and the threshold levels for yellow events and red events, which are defined for each maneuver type and fine-tuned by the vendor for the type and characteristics of the vehicle. The yellow and red event threshold levels defined for each maneuver and vehicle type combination were based on more than 7 years of extensive research and fleet validation across a broad set of vehicle types and operating environments by the vendor. However, because the numerical thresholds are proprietary data, they are not available to the research team. The research team has inferred, as a general rule, that a yellow event involves sufficient forces on the vehicle to cause passenger discomfort while a red event represents a very aggressive driving maneuver that could result in injury or cause vehicle passengers or cargo that are not securely restrained to be shifted within the vehicle. Depending on the severity of the driver action, the changeover from a yellow to a red event is estimated to occur at around 10–15 ft/s^2. The safety monitoring system also calculates a Safety Score, which provides a week-by-week summary or assessment of how safely the driver is operating. The safety monitoring system technology also collects other safety data not used in this study.

The fuel-monitoring system was the primary telematics system that provided data from the ECU on the following vehicle performance parameters:

- Speed every 30 minutes (converted in the data analysis into percent of total VMT at > 65 mi/h). The speed was determined by the fuel monitoring system using the ECU; it was independent of and not compared with the speed determined by the safety monitoring system's GPS.
- Engine RPM every 30 minutes (converted in the data analysis into percent of VMT at > 1,500 RPM).
- Fuel consumption every 30 minutes (converted in the data analysis into mi/gal).

The fuel monitor vendor created the onboard components to facilitate communication between the vehicle's ECU and the low-earth orbit satellite. The vendor also developed the "bus" (a communication system that transfers data between components inside a computer) to manage messaging to and from the vehicle's satellite communication modem and the back-end business applications. The fuel monitoring system also collects data on vehicle performance parameters other than fuel consumption, which are not used for this study.

The research team recognized one additional important parameter—load-specific fuel consumption or ton mi/gal. The team worked with the truck manufacturer to explore numerous electronic methods to collect this data for this parameter; however, the effort was unsuccessful as this technology is only now emerging. The team also collected driver logs that included approximate weights of loads from the fleet management, which can potentially be inserted manually into a database for future calculation of this metric.

Because the sleeper cabs were assigned, the driver and the data from a sleeper cab could be linked together from the records. However, because the pilot day cabs were not assigned, a special system was installed in the pilot day cabs to allow identification of the driver. Each driver had a unique key, and as he or she entered a vehicle, he or she would swipe a key across a sensor to register a driver profile. Once the device was installed, the system would then track driver movements from vehicle to vehicle. However, the team did not use this option in this study because the fleet management provided the team with daily driver logs across all groups.

The parameters obtained from any vehicle will contain the profiles of all drivers, and thus, are not of much use when looking at improving fleet performance. Drivers are generally not assigned to any one vehicle (except sleeper cabs); thus, tracking their movement among vehicles is crucial. The detailed daily logs obtained from the fleet management allowed the research team to track a driver across all vehicle groups.

It is emphasized that the two telematics technologies used in this study operate independently of each other. As noted above, the fuel monitoring system measures a range of parameters directly from the vehicle ECU. The safety monitoring system uses an accelerometer unit installed in the cab to measure gravitational (g) forces, which are proxies for safety. The intent of this study was not to evaluate the outputs of the two technologies against each other but rather to determine any improvements in safety and fuel consumption through the intervention process and whether a correlation between safety and fuel consumption exists.

2.1.5 Project Stages

The project was conducted in the following stages as Figure 1 shows and as described below:

- Stage 1. Baseline data collection (November 2010–December 2011).
- Stage 2. Pilot driver awareness/information.
  - 2A—Pilot driver aware of being monitored (December 2010–January 2011).
  - 2B—Pilot driver provided with vehicle-specific information on speed, RPM, and fuel consumption on a weekly basis (January–April 2011).
- Stage 3. Pilot drivers were made aware that their behavior was being monitored with feedback provided through in-cab display for speeding and unsafe events (May 2011).
- Stage 4. Pilot drivers were rated, and pilot drivers with below-threshold ratings were provided with coaching (June 2011).
- Stage 5. Stage 4 plus incentives (July–August 2011).
- No intervention—All interventions cease (not called a stage) but data collection continues.

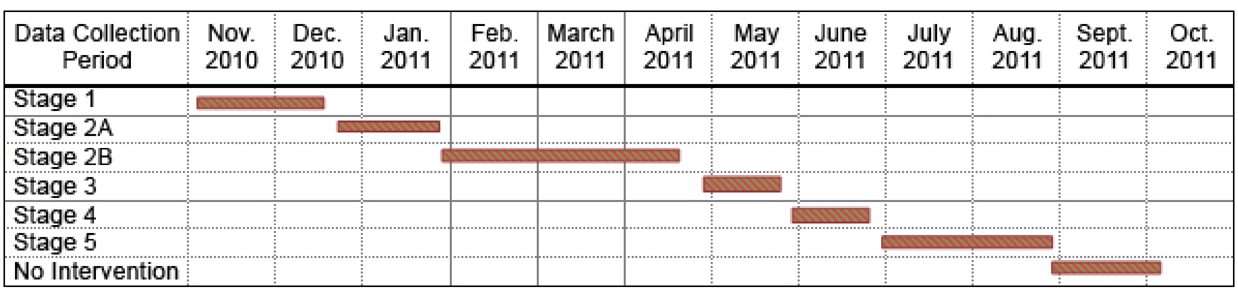

Figure 1. Chart. Project schedule.

Each vehicle group (i.e., day cabs and sleeper cabs) was separated into two subgroups—the control group and the pilot group. Thus, the four combinations were control day cab group, pilot day cab group, control sleeper cab group, and pilot sleeper cab group.

The team used the two control groups as a running baseline throughout the study; the drivers in the control groups were not aware they were being monitored. Only the drivers in the pilot groups were aware that they were being monitored at intervals to observe changes in driving performance throughout the respective stages. The research team worked with the management team to select 17 drivers for the pilot day cab group to follow throughout the study. This was important because of the nature of day cabs, wherein a driver is not permanently assigned to a vehicle. In general, each pilot sleeper cab driver is consistently assigned the same vehicle. The control groups were as close as practicable—but not absolutely identical—to the pilot groups because the research team could not control for all variables, such as operating under different weather conditions, different routes, and different road conditions. The intent of the control group was to provide a reference point (in addition to the baseline) against which to compare changes in driving performance of the pilot group and to observe any peculiar trends occurring outside the pilot group. The pilot group data are generally compared with the baseline established during Stage 1 except that broad comparisons are made between the pilot and the control groups during the winter months (when fuel consumption is known to vary).(16) The control group results are provided for all stages within the study. For the final stage (Stage 5), the control day cab group is compared with the pilot day cab group, and the control sleeper cab group is compared with the pilot sleeper cab group.

Stage 1. The data collection for the baseline (Stage 1) ran for slightly less than 2 months. The team used both fuel economy and safety telematics technologies on all vehicle groups (day cabs and sleeper cabs) to collect the data. During the baseline period (or blind profile period) drivers were unaware that their driving was monitored; thus, the performance data collected by the research team can be assumed to reflect the normal driving behavior in all groups. The purpose of collecting the data on the control groups in each of the vehicle categories was to provide a continuous reference throughout the study period. The control groups were not true identical control groups because the research team could not control for all variables. Further, as the study progressed, it became harder to isolate the control group drivers from the pilot group drivers.

Stage 2. During Stage 2A, drivers of both pilot groups received an initial memorandum that an independent research team of consultants was collecting performance data from the trucks they drove to assess safety and fuel economy. The fleet manager distributed the memoranda directly to each driver and placed a small (4 inches x 2 inches) notice on the dashboard of each pilot vehicle as a reminder. Six weeks after Stage 2B was initiated, fleet management began to receive data for use in day-to-day fleet operations review and in discussions with drivers. Information was provided to drivers, but there was no coaching that targeted specific drivers in Stage 2. The research team compiled the vehicle operations data and emailed it to fleet management on a weekly basis. This stage continued until late April 2011. During this period, fleet managers had access to the fuel-monitor vendor's Web site where they could review all data collected on each vehicle. The Web data were updated every 30 minutes.

Stage 3. Just prior to activating Stage 3, the pilot day cabs were fitted with a special driver key that potentially allowed the team to track the drivers throughout the remainder of the study. Safety monitoring in-cab display units were installed on all pilot vehicles. The intent was that drivers would be aware that they were being monitored and reminded through the in-cab light display of speeding (i.e., exceeding 65 mi/h) as determined by the safety monitoring system (using GPS). A speeding notification was shown as a blinking green light. The in-cab display would also display yellow and red events. Stage 3 began by activating the in-cab display, which ran for approximately 1 month. Similar to Stage 2, there was no targeted coaching. No feedback was provided for any of the parameters tracked by the fuel monitoring system (namely, driving more than 65 mi/h, excessive RPM, or fuel economy as determined by the ECU).

Stage 4. Fleet managers received the same data as in the previous stages—fuel economy and safety data. They were instructed to use the safety data to coach the drivers where there appeared to be a pattern of safety deficiencies, such as speeding (as determined by GPS), hard braking, or sudden acceleration. This stage ran for approximately 4 weeks. No feedback was provided for any of the parameters monitored by the fuel monitoring system (such as excessive RPM or fuel economy).

Each driver was rated with an overall Safety Score which was generated by determining the number of red or yellow events that took place over 10 hours of driving, on average. Drivers were targeted for coaching if their overall Safety Scores were greater than 50 percent of the fleet average. Drivers with Safety Scores above this threshold were privately coached on their scores and what was expected of them.

Coaching can take as little as 10 seconds passing in a hall (“I saw that your speeds are consistently high; I need you to watch the speed!”) or can take up to 30 minutes when details are needed. Fleet managers were able to review the driver score trends and view through geographic mapping features where exactly the risks were taking place in order to assess potential mitigating actions. Fleet managers did not spend more than 2 hours per week on coaching drivers during Stage 4.

Stage 5. This stage combined Stage 4 with an incentive program. Drivers in both the pilot day cab and pilot sleeper cab groups received weekly gift cards worth $25 each for best safety improvement (as defined in Stage 4) and best fuel economy during the previous week. This reward was publicized across the pilot fleet to recognize good driving behavior. On a monthly basis, the incentives increased to $100 for best overall 4-week improvement for safety, and separately, for fuel consumption. Fleet management provided all incentives. Stage 5 concluded after 8 weeks. The duration for Stage 5 was limited by the study period.

Stage 5 was followed by a period of no intervention for about 5 weeks to assess if any performance gains could be maintained over time.

2.1.6 Evaluation Process

The team used the retrospective approach (comparison of performance before driver intervention and after driver intervention) to evaluate the effectiveness of the telematics systems in improving driving behavior. Stage 1 is the period before any driver intervention, and Stages 2–5 refer to the period after implementing the telematics systems and other interventions. Data collected during the intervention (Stages 2–5) were compared to Stage 1 (baseline) of the respective pilot group. Performance was measured using the parameters listed in Section 2.1.4 for the before-and-after driver intervention process and compared to determine any resulting safety and fuel economy changes from the overall intervention process.

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3. PERFORMANCE MEASURES

3.1 FOCUS

Driving performance can be monitored and measured using certain parameters. One category of driving performance parameters falls into safety, and the second category falls into fuel economy. Safety is the more important of the two categories. As mentioned previously, telematics systems do not monitor safety, but they do use safety proxies, such as speeding, harsh accelerations, hard braking, and sudden lane changes. This chapter describes the kinds of hypotheses about safety improvement that can be tested with data about safety proxies collected by a telematics system.

Fuel costs are a significant portion (28–38 percent) of overall motor carrier operating costs, and technologies that monitor fuel consumption and help provide feedback to change driving techniques have tremendous potential for improving fuel economy. Furthermore, by implementing telematics systems, coupled with driver intervention (automated in-cab feedback and coaching) fleet managers have the potential to significantly enhance their profit margins. This chapter will also describe the kinds of hypotheses for improving fuel economy that can be tested with data about fuel consumption collected by a telematics system.

In this chapter, the hypotheses will be discussed in the following order: unsafe (yellow and red) events, speeding, RPM history, and fuel economy.

3.2 HYPOTHESES

The intent is to examine to what extent improvements, if any, can be made in safety and fuel economy from the use of a telematics system to monitor driver performance and from an intervention process to provide coaching and rewards for modifying driver behavior.

Data collected from the field study was used to assess the possibility of a relationship between safe driving and fuel-efficient driving. Performance was measured using the parameters established in Section 2.1.4 throughout all stages of the field study.

3.2.1 Unsafe Events (Red and Yellow)

Safety should always be the first priority of a motor carrier operation. Safe driving performance can be measured by telematics systems using proxies, such as the occurrences of unsafe events (e.g., hard braking, rapid acceleration, and sudden lane change) normalized over some unit, such as VMT. The lower the frequency of such unsafe events, the safer is the driving performance. Unsafe events may be categorized, based on their severity. Section 2.1.4 describes how such unsafe events are categorized as moderately severe (yellow event) or highly severe (red event). A hypothesis can be tested to evaluate the extent to which the number of unsafe (yellow and red) events per mile can be reduced by monitoring driver performance using a telematics system and using an intervention process (i.e., feedback, coaching, and rewards) to modify driver behavior. Table 1 articulates the hypothesis for unsafe events, the performance measure, and the source of data for measurement.

Table 1. Hypothesis for unsafe events.

Evaluation Objectives	Hypothesis	Measure	Performance Data Sources
Assess reduction in frequent sudden accelerations or decelerations (see Section 2.1.4 for more details).	Driver monitoring and related intervention process will reduce unsafe driving behavior.	Compare yellow (less severe) and red (more severe) events per 100 miles traveled per vehicle between pre- and post- intervention stages.	Data from safety monitoring technology.

3.2.2 Speeding

Driver speed is another important safety proxy. Furthermore, if the driving speed is much more than 65 mi/h, then fuel economy is expected to drop significantly.[1,6,17,18,19] Percentage of miles driven at speeds greater than 65 mi/h is calculated from the vehicle ECU through the fuel monitoring telematics system. A hypothesis can be tested to evaluate the extent to which speeding can be reduced by monitoring driver performance using a telematics system and using an intervention process to modify driver behavior. Table 2 articulates the hypothesis for driving speed, the performance measure, and the source of data for the measurement.

Table 2. Hypothesis for driving speed.

Evaluation Objectives	Hypothesis	Measure	Performance Data Sources
Assess reduction in driving at high speed.	Driver monitoring and related intervention process will help drivers reduce distances driven at high speeds.	Compare percentage of miles traveled by vehicles at > 65 mi/h between the pre- and post-intervention periods.	Data from fuel consumption using vehicle ECU (not from safety monitoring system) using GPS.

3.2.3 RPM History

Fuel economy also depends on engine operation, such as engine RPM. The best fuel economy is expected when drivers operate a vehicle at a certain range of RPM. Generally, a truck must maintain around 1,300 RPM[14,20] for maximum fuel economy, which the industry calls the "sweet spot." Table 3 articulates the hypothesis for engine RPM.

Table 3. Hypothesis for engine RPM.

Evaluation Objectives	Hypothesis	Measure	Performance Data Sources
Assess reduction of driving at high RPM.	Driver monitoring and related intervention process will help drivers reduce the distances traveled in excessive RPM range.	Compare percentage of miles traveled by vehicle at > 1,500 RPM between pre- and post-intervention periods.	Data from vehicle ECU.

3.2.4 Fuel Economy

Fuel economy is the last major parameter to be measured during the demonstration of a telematics system in fleet operation. Most of the time, driver behavior plays an important role in fuel economy. The major question to be answered by the field study is whether monitoring drivers and utilizing driver intervention (i.e., rewards) causes drivers to modify driving behaviors in order to achieve better fuel economy. Table 4 summarizes the hypothesis for fuel economy, the performance measure, and the source of data for the measurement.

Table 4. Hypothesis for fuel economy.

Evaluation Objectives	Hypothesis	Measure	Performance Data Sources
Assess improvement in fuel consumption.	Driver monitoring and related intervention process will help improve fuel economy.	Compare fuel consumption in mi/gal/vehicle—pre- and post-intervention periods.	Data from vehicle ECU.

3.3 STATISTICAL ANALYSIS

The research team used statistical tests to better understand whether changes observed in the performance parameters being measured are attributable to driver behavior modification through driver intervention or simply chance. The statistical analyses performed to assess the observed changes include:

- The Mann-Whitney *U* test is used to determine whether differences between the mean gallons of fuel consumed per mile driven in the before-and-after driver intervention process are statistically significant (expressed as the *z*-statistic).
- The *t*-test is used to determine if the differences in speeding, RPM, and unsafe (red and yellow) events in the before-and-after driver intervention periods are statistically significant.

3.3.1 Mann-Whitney *U* Test

The research team used the Mann-Whitney *U* test to determine if differences in the mean of fuel consumed (miles per gallon) before and after driver intervention are statistically significant. The Mann-Whitney *U* test is a nonparametric test for assessing whether two nonparametric samples are equal. To calculate the test statistic, all observations from both groups are arranged in a single ranked series (as shown in Figure 2). Summing up the overall ranks for the first group provides the variable R_1. U is then given by the following formula:

$$U = R_1 - n_1(n_1+1)/2$$

Figure 2. Formula. Equation to find *U*.

where n_1 is equal to the sample size of the first group. For sufficiently large samples (i.e., larger than 20), a normal approximation is used to calculate the *z*-statistic is shown in Figure 3:

$$z = (U—\mu_U)/\sigma_U$$

Figure 3. Formula. Equation to find *z*.

Z is a standard normal deviation whose significance can be checked using the standard tables of the normal distribution. The variables *mu* subscript *u* and *sigma* subscript *u* are the mean and standard deviation, respectively, of *U* if the null hypothesis is true, and are given by the equations shown in Figure 4:

$$\mu_u = n_1 n_2 / 2$$
$$\sigma_u = \sqrt{[n_1 n_2 (n_1 n_2 + 1)/12]}$$

Figure 4. Formula. Equations to find variables *Mu* subscript *u* and *Sigma* subscript *u.*

where n_1 is the sample size of the first group and n_2 is the sample size of the second group. A two-tailed test is used in which the null hypothesis states that there is no difference between the before-and-after periods. The two-tailed test was used, as the effectiveness of the driver intervention process was not known, and a one-tailed test requires the direction of the difference to be known or specified prior to the analysis. The two-tailed test is more stringent than the one-tailed test and requires a larger difference between the means in order to be statistically significant.

4. FLEET PERFORMANCE DATA—RESULTS/DISCUSSION

4.1 DATA SCREENING AND ANALYSIS

The research team downloaded performance data on a weekly basis. Initial data screening revealed a short data gap caused by malfunctioning telemetry equipment. To streamline the analysis, the team eliminated the time period without data from the vehicle analysis.

All data were analyzed by stages. The team compared the analyzed results to the previous stages to evaluate any progress in driver behavior and efficacy of intervention activities at each stage, as appropriate. The overall fleet performance, rather than individual driver performance, was the focus of the analysis.

For context, the total miles traveled by all vehicles included in the study exceeded 3.6 million. This translates to more than 50,000 driver hours. The day cabs were tracked for approximately 1.6 million miles, and sleeper cabs were tracked for more than 2 million miles. When used, the term "intervention process" or "process" relates to the combined effect of driver awareness of being monitored, in-cab display feedback to the driver, coaching, and incentives for the driver, as included in Stages 2A, 2B, 3, 4, and 5. No feedback or coaching was provided on RPM history or fuel economy in Stages 2 to 4. However, in Stage 5, drivers received rewards for fuel economy improvement.

Figures 5 to 14 illustrate the results of the study showing how a driver performance parameter progresses through the study period (see Figure 1 to determine which stage occurred at what time during the study period). The data in Tables 5 to 29 present the measured value of a driver performance parameter at various stages. A test of significance was performed for all performance parameters at Stages 2 to 5 compared to the baseline (Stage 1).

The results of the data analysis will be discussed in the same order as the hypotheses presented in the last chapter: unsafe (yellow and red) events, speeding, RPM history, and fuel economy.

4.2 STUDY RESULTS

4.2.1 Unsafe Events (Yellow Events and Red Events)

The research team used the safety-monitoring telematics system to collect data on yellow and red events during the 2010–11 study period. The study period was too short to collect sufficient data to observe any reduction in crashes and crash severity because crashes are generally rare events.

The data illustrates that the number of yellow or red events spikes during the winter months. While this may be expected because of environmental conditions, the team believes that to understand these trends and to assess the full impacts, data must be collected over an extended period spanning 36–60 months. The reader should recognize the limitations of a short-term study.

Figure 5 and Figure 6 provide a plot for day cab groups and sleeper cab groups, respectively, relating to the number of yellow events per 100 VMT as a function of time during the 2010–11 study period. The data shown in Table 5 show a 56-percent reduction in yellow events per 100 VMT for the pilot day cab group between Stage 1 (November and December) and Stage 5 (July and August). Note that in Stage 4, feedback and coaching were provided to drivers specifically on yellow events; in Stage 5, feedback, coaching, and rewards were provided to drivers specifically on yellow events. Even though this reduction is large for the pilot day cab group, it is not meaningful when compared with a 76-percent reduction in yellow events per 100 VMT for the control day cab group between Stage 1 and Stage 5 (calculated from the data presented in Table 6). This phenomenon could be due to the fact that the control day cab drivers happened to be on less congested routes (where yellow events are less likely to occur) than the pilot day cab drivers between February (Stage 2B) and August (Stage 5). The authors did not have control over route assignments and assumed that routes were randomly assigned.

The data shown in Table 7 illustrate that the pilot sleeper cab group experienced a statistically-significant reduction in frequency of yellow events. Pilot sleeper cab drivers had an average of 0.73 yellow events per 100 VMT at Stage 5 compared with a baseline of 1.62—a 55-percent decrease in yellow events per 100 VMT. The 55-percent reduction in yellow events for the pilot sleeper cab group compares to a 22-percent reduction in yellow events experienced by the control sleeper cab group during the same time period (calculated from the data presented in Table 8). The 55-percent reduction is statistically significant.

The overall trend of both pilot groups compared to the control groups suggest that the intervention process dramatically reduced the less severe yellow events. Comparing the pilot day cab group to the pilot sleeper cab group, the data illustrate that sleeper cabs appear to benefit the greatest through the intervention process (see Figure 5 and Figure 6).

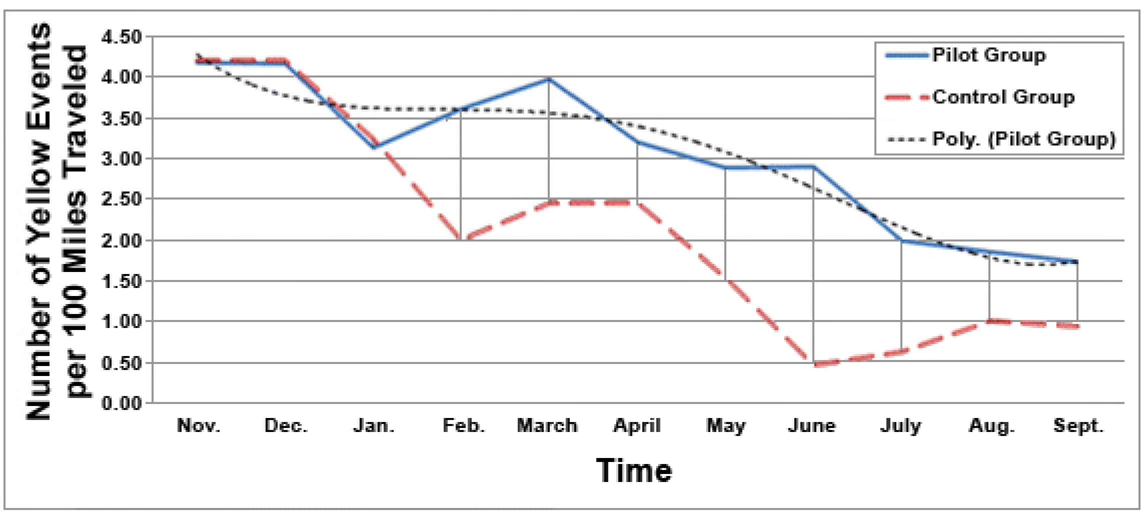

Figure 5. Line graph. Yellow events per 100 VMT for day cab group.

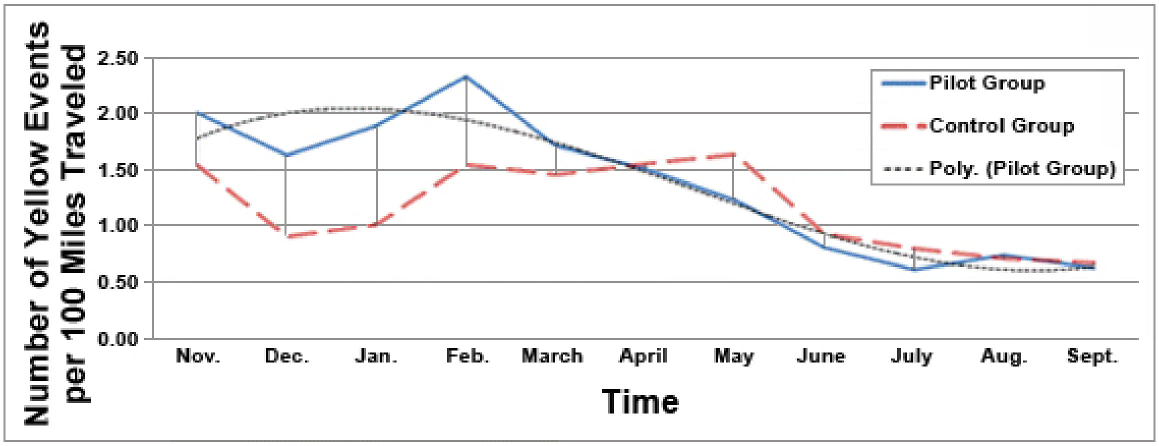

Figure 6. Line graph. Yellow events per 100 VMT for sleeper cab group.

Table 5. Statistical analysis of yellow events per 100 VMT for pilot day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	4.17	3.12	3.97	2.88	2.89	1.84
N	76	193	28	43	60	60
SD	5.37	3.66	2.73	3.47	3.81	2.0
t Test	N/A	1.56	0.24	1.58	1.62	3.48
Significant Difference (0.05)	N/A	No	No	No	No	Yes

Table 6. Yellow events per 100 VMT for control day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	4.20	3.24	2.44	1.53	.0.46	1.00

Table 7. Statistical analysis of yellow events per 100 VMT for pilot sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	1.62	1.6202	1.71	1.22	0.80	0.73
N	160	160	149	191	171	107
SD	2.56	2.5591	5.44	3.10	1.41	0.85
t Test	N/A	N/A	-0.17	1.31	3.59	4.06
Significant Difference (0.05)	N/A	No	No	No	Yes	Yes

Table 8. Statistical Analysis of yellow events per 100 VMT for control sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	0.90	1.00	1.45	1.63	0.92	0.70

Figure 7 and Figure 8 provide a plot for the day cab groups and the sleeper cab groups, respectively, relating to number of red events per 100 miles traveled as a function of time during the 2010–11 study period. From the data shown in Table 9, a reduction of 63 percent in red events per 100 miles traveled can be calculated for the pilot day cab group between Stage 1 (November and December) and Stage 5 (July and August). Note that in Stage 4, feedback and coaching were provided to drivers specifically on red events; in Stage 5, feedback, coaching, and rewards were provided to drivers specifically on red events. Albeit large, the 63-percent reduction is not meaningful in comparison with the 87-percent reduction between Stage 1 and Stage 5 in the control day cab group (calculated from the data presented in Table 10). Again, this phenomenon could be due to the fact that the control day cab drivers happened to be on less congested routes (where red events are less likely to occur) than the pilot day cab drivers between February (Stage 2B) and August (Stage 5) similar to the phenomenon found for yellow events. The authors did not have control over route assignments and assumed that routes were randomly assigned.

The data shown in Table 11 illustrate that the pilot sleeper cab group experienced a 47-percent reduction in red events per 100 miles traveled. Pilot sleeper cab drivers had an average of 0.08 red events per 100 miles traveled at Stage 5 compared with a baseline of 0.15. This 47-percent decrease compares to a 60-percent increase in the control sleeper cab group calculated from the data presented in Table 12. However, the 47-percent decrease for the pilot sleeper cab group is not statistically significant. The team believes that while this could be a good safety outcome, the low number of red events does contribute to the low level of statistical significance.

On the other hand, pilot sleeper cab drivers had an average of 0.06 red events per 100 miles traveled at Stage 4 compared with a baseline of 0.15. This 60-percent decrease between Stages 1 and 4 contrasts with a 20-percent increase of red events in the control sleeper cab group between Stages 1 and 4, calculated from the data presented in Table 12. Furthermore, the 60-percent pilot sleeper cab group decrease of red events between Stages 1 and 4 is statistically significant.

Sleeper cabs operated in an environment where the probability of such events occurring per mile driven, as shown in Table 11 and Table 12, was often less than the day cab group, as shown in Table 9 and Table 10. In fact, the pilot day cabs experienced about three times the number of red events per 100 miles traveled as the pilot sleeper cabs.

The decrease in frequency of yellow events during the driver intervention process was not accompanied by an increase in red events (severe unsafe events). All of the data to date show that drivers exhibit safer driving behavior at the end of the intervention process (which is Stage 5 in July and August) than prior to the intervention process (which is Stage 1 in November and December).

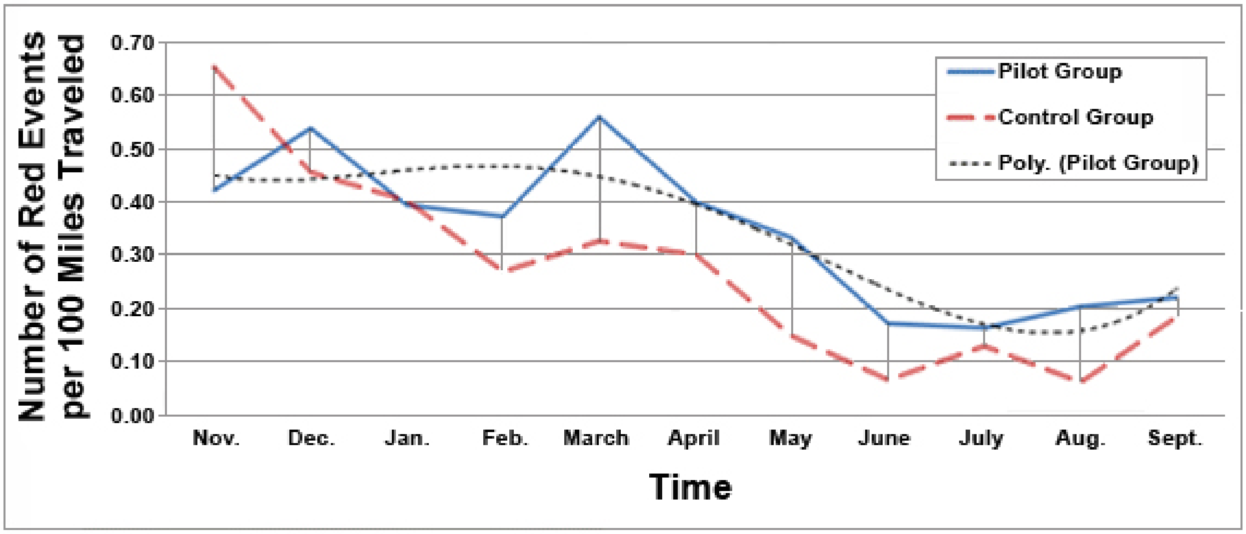

Figure 7. Line graph. Red events per 100 VMT for day cab group.

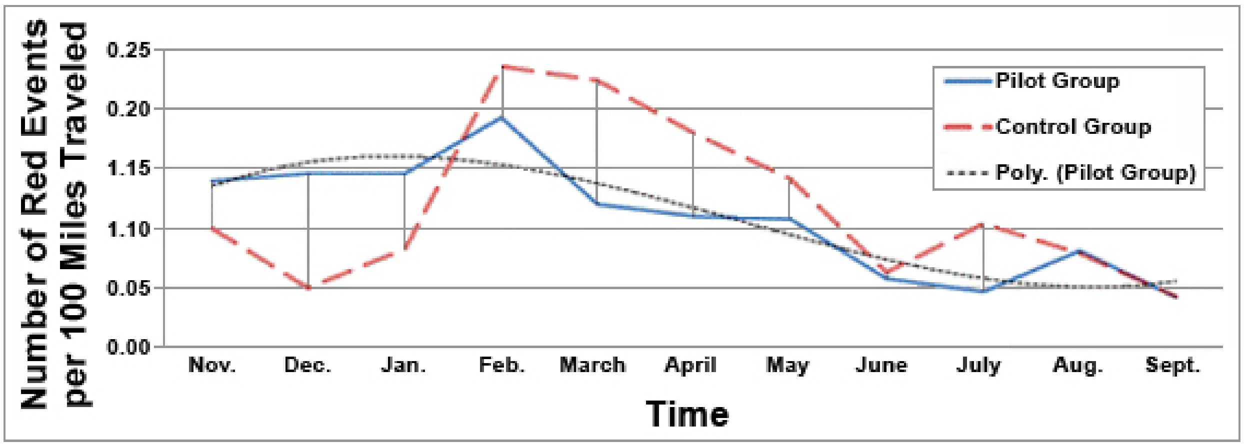

Figure 8. Line graph. Red events per 100 VMT for sleeper cab group.

Table 9. Statistical analysis of red events per 100 VMT for pilot day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average ($\bar{X}$)	0.54	0.39	0.56	0.33	0.17	0.20
N	76	193	28	43	60	60
SD	2.10	0.83	0.70	0.60	0.49	0.39
t Test	N/A	0.58	-0.08	0.79	1.46	1.35
Significant Difference (0.05)	N/A	No	No	No	No	Yes

Table 10. Red events per 100 VMT for control day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average ($\bar{X}$)	0.46	0.40	0.32	0.15	0.05	0.06

Table 11. Statistical analysis of red events per 100 VMT for pilot sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	0.15	0.1457	0.12	0.11	0.06	0.08
N	160	392	149	191	171	107
SD	0.34	0.4556	0.47	0.51	0.21	0.26
t Test	N/A	0.0129	0.48	0.83	2.84	1.79
Significant Difference (0.05)	N/A	No	No	No	Yes	No

Table 12. Red events per 100 VMT for control sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	0.05	0.08	0.22	0.14	0.06	0.08

4.2.2 Speeding

The research team used the operations management telematics system to collect data on speeding during the 2010–11 study period. Figure 9 and Figure 10 provide plots for the day cab group drivers and the sleeper cab group drivers, respectively, for percent of miles traveled at > 65 mi/h as a function of time during the study period. The trend in reduction of miles driven at > 65 mi/h improves over time for the pilot day cab drivers and the pilot sleeper cab drivers beyond Stage 2B (February–April) through the successive, more involved driver intervention (Stages 3, 4, and 5). The trend line beyond Stage 2B is positive with an R^2 value (from linear regression analysis) of approximately 0.92. In comparing the pilot day cab group to the pilot sleeper cab group overall, the data illustrate that sleeper cab drivers appear to show a greater reduction in percent of miles driven > 65 mi/h through the intervention process. The data shown in Table 13 and Table 15 illustrate that both pilot day cab and pilot sleeper cab group drivers, respectively, experienced significant benefits from the intervention process—day cab drivers had an average of 12.28 percent of miles driven more than 65 mi/h at Stage 5 (July and August) compared with a baseline of 18.04 percent of miles driven > 65 mi/h—a 32-percent decrease. Sleeper cab drivers had an average 16.22 percent of miles driven at > 65 mi/h at Stage 5 compared with a baseline (Stage 1) of 28.1 percent of miles driven at > 65 mi/h—a 42-percent decrease. When a Stage 5 comparison between the pilot and the control groups is made, sleeper cab drivers had a decrease of 42 percent (as shown in Table 18) versus 33 percent for day cab drivers (as shown in Table 17).

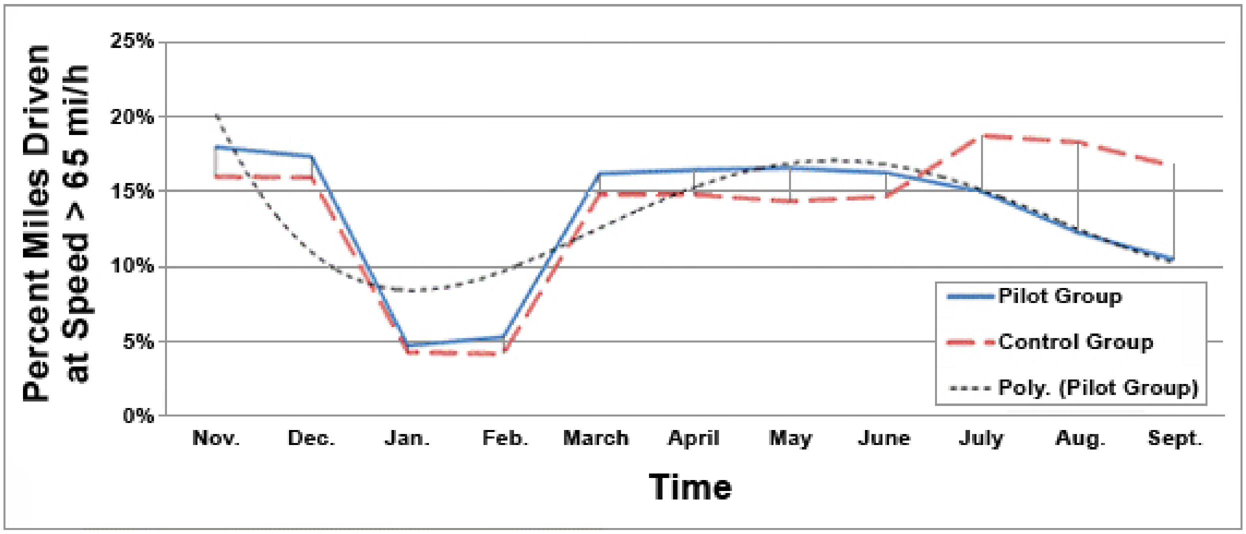

Figure 9. Line graph. Percent of miles driven at speeds > 65 mi/h for day cab group.

Note that during the winter months, all groups exhibited significant reductions in percent of miles driven at > 65 mi/h. The study team can only assume that reduced driver speeds are the result of drivers adjusting to winter weather effects, such as reduced visibility and/or poor road surface conditions. This is to be expected because both the pilot and the control vehicle groups operate in the northeast areas of the U.S., where weather conditions deteriorate during the winter months (from late January through early April). Ignoring the winter weather effect, the R^2 value trends to 0.92 for the pilot group.

Overall, as the result of the intervention process, drivers from both pilot day cab and pilot sleeper cab groups modified their driving behavior. During the first intervention (Stage 2), drivers from both pilot groups showed minor improvements, though not significant. At Stage 3 (May), feedback (blinking green lights on the in-cab display) on speeding was introduced to the drivers of the pilot day cab and the pilot sleeper cab groups, and both pilot groups started to show a slight but statistically-significant drop in percent of miles driven at > 65 mi/h (see Table 13 and Table 15). After Stage 4, the trend of both pilot groups suggests that the intervention process dramatically reduced percent of miles driven at speeds > 65 mi/h. This reduction in percent of miles driven at > 65 mi/h was greater at Stage 4 (June) and Stage 5 (July and August).

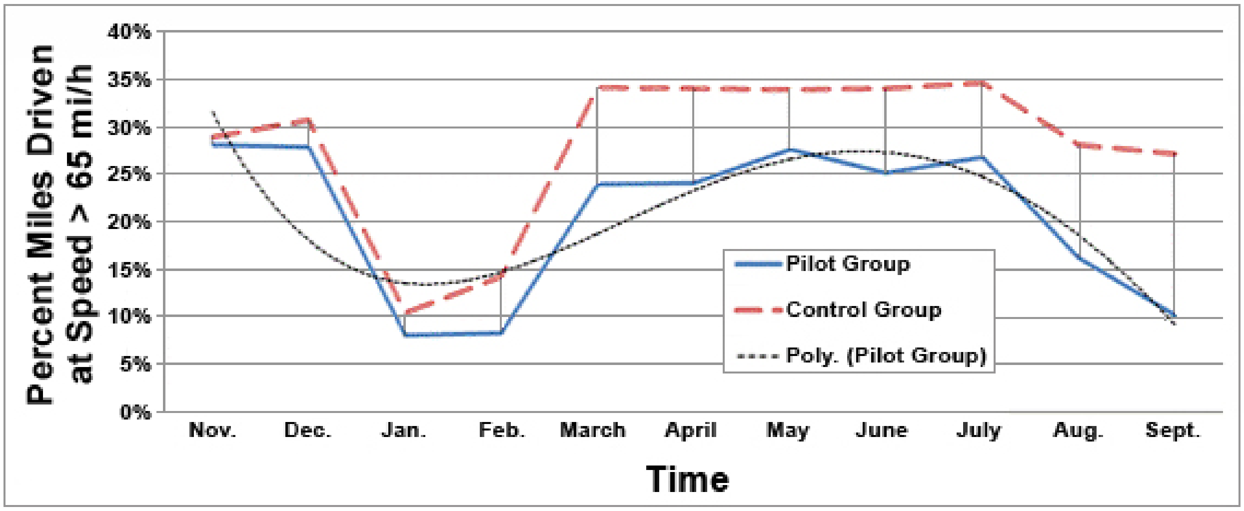

Figure 10. Line graph. Percent of miles driven at speeds > 65 mi/h for sleeper cab group.

Table 13. Statistical analysis of percent miles driven at > 65 mi/h for pilot day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	0.15	0.1457	0.12	0.11	0.06	0.08
N	160	392	149	191	171	107
SD	0.34	0.4556	0.47	0.51	0.21	0.26
t Test	N/A	0.0129	0.48	0.83	2.84	1.79
Significant Difference (0.05)	N/A	No	No	No	Yes	No

Table 14. Percent of miles driven at > 65 mi/h for control day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	16.05	15.96	14.81	14.41	14.70	18.30

Table 15. Statistical analysis of percent of miles driven at > 65 mi/h for pilot sleeper cab group.

	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	28.10	27.8610	23.98	27.59	25.11	16.22
N	6602	5491	6682	7510	6536	4009
SD	6.61	6.6832	10.05	7.92	7.17	11.55
t Test	N/A	1.9898	27.98	4.21	24.91	59.48
Significant Difference (0.05)	N/A	No	Yes	Yes	Yes	Yes

Table 16. Percent of miles driven at > 65 mi/h for control sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	28.96	30.66	34.05	33.89	33.96	28.12

Table 17. Comparison of percent of miles driven at > 65 mi/h for pilot and control day cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (*X*)	18.30	12.28
N	1211	1122
SD	4.13	6.50
t Test	N/A	-17.48
Significant Difference (0.05)	N/A	Yes

Table 18. Comparison of percent of miles driven at > 65 mi/h for pilot, control sleeper cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (*X*)	28.12	16.22
N	3196	4009
SD	8.80	11.55
t Test	N/A	49.62
Significant Difference (0.05)	N/A	Yes

4.2.3 RPM History

The operating RPM of a truck engine is an important factor that affects fuel economy. The study team used data collected by the safety measurement systems to gather data on RPM history. The RPM history is obtained by calculating the percent of miles traveled at > 1,500 RPM. The percent of total VMT at high RPM operation is calculated as the VMT at > 1,500 RPM divided by the total VMT of the trip on a 30-minute basis.

Figure 11 and Figure 12 provide plots for the day cab group drivers and the sleeper cab group drivers, respectively, for percent of miles traveled at more than 1,500 RPM as a function of time during the 2010–11 study period. The trend improves over time in both driver groups (pilot day cabs and pilot sleeper cabs) as the study progresses after Stage 1 (baseline period—November and December) through the successive, more involved driver intervention stages. The trend line beyond Stage 2B (beyond April) is positive with an R^2 value of approximately 0.88. The data shown in Table 19 illustrate that the pilot day cab group drivers experienced an increase in percent of miles traveled at > 1,500 RPM; pilot day cab drivers had an average of 6.76 percent of miles driven > 1,500 RPM at Stage 5 (July and August) compared with a baseline of 5.31 percent of miles driven at > 1,500 RPM—a 27 percent increase. However, note that with the onset of Stage 4 (in June), the day cab trend is downward, which continues beyond the intervention period (Stage 5), and the trend does not return to the baseline level. The day cab drivers operate on congested routes with moderate-to-heavy traffic volumes, which accounts for the higher distances at excessive operating RPM values.

For sleeper cab drivers, the data shown in Table 21 illustrate that the group showed a significant reduction in the percent of miles traveled at the > 1,500-RPM range; pilot sleeper cab drivers had an average of 1.07 percent of miles traveled > 1,500 RPM at Stage 5 compared with a baseline of 2.06 percent for distances driven at > 1,500 RPM—a 48-percent decrease. This is expected, as the sleeper cab drivers operate during periods of less traffic congestion, and thus they travel less distance in the higher RPM range.

When the pilot and the control groups are compared at Stage 5, sleeper cab drivers (as shown in Table 24) had a higher decrease in percent of miles traveled > 1,500 RPM—76 percent compared to 57 percent for day cabs (as shown in Table 23). The overall trend of both pilot day and sleeper groups compared to the control day and sleeper groups suggests that the intervention process dramatically reduced percent of miles traveled at > 1,500 RPM even though no feedback or coaching was specifically provided on RPM. This reduction was greater when drivers received both coaching and rewards. However, after introducing Stage 4, the percent of miles driven at > 1,500 RPM was reduced dramatically in both pilot groups. Overall, the data indicated that the sleeper cab group (the long-haul trucks) has the most to gain from monitoring and the driver intervention process. Even though no feedback, no coaching, and no incentives were provided to drivers during the intervention process for reducing RPM to < 1,500, the focus of the intervention process on yellow and red events seems to have had an indirect effect on reducing RPM to < 1,500 in both pilot groups.

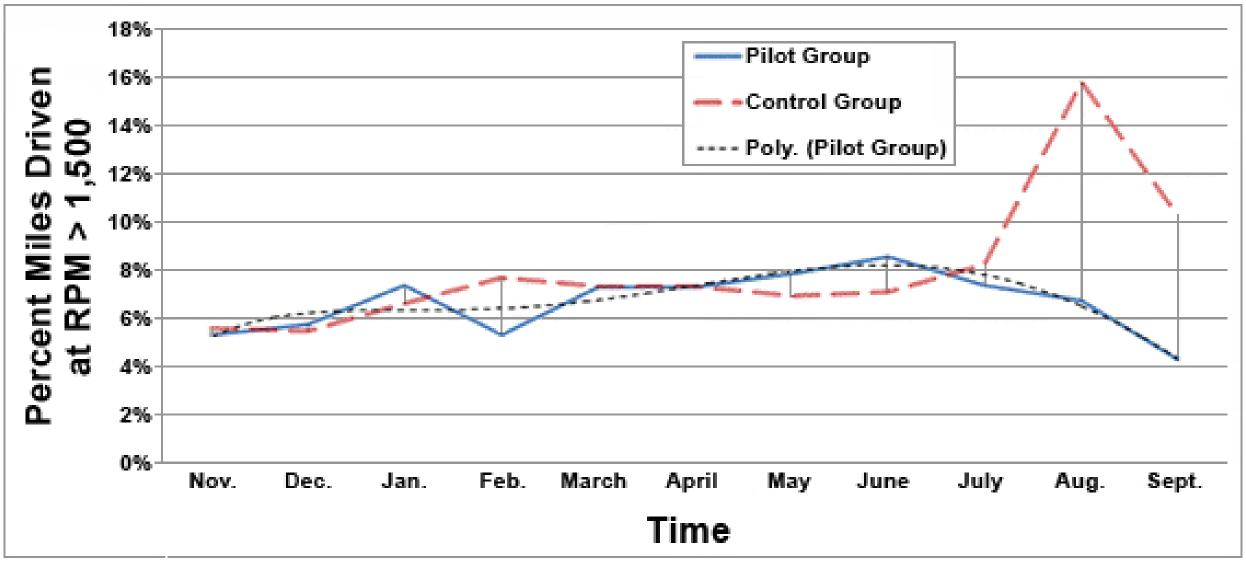

Figure 11. Line graph. Percent of miles traveled at > 1,500 RPM for day cab group.

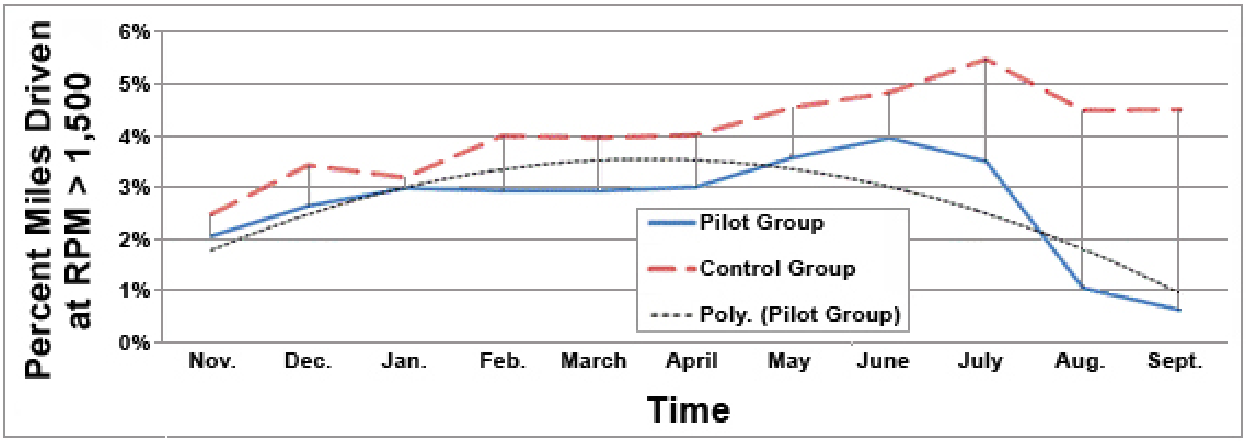

Figure 12. Line graph. Percent of miles traveled at > 1,500 RPM for sleeper cab group.

Table 19. Statistical analysis of percent of total VMT at > 1,500 RPM of pilot day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	5.31	5.76	7.28	7.84	8.57	6.76
N	2060	1037	556	805	1304	1122
SD	2.60	2.76	2.32	2.09	3.46	4.01
t Test	N/A	-4.36	-17.25	-27.01	-29.13	-10.86
Significant Difference (0.05)	N/A	No	Yes	Yes	Yes	Yes

Table 20. Percent of total VMT at > 1,500 RPM of control day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	5.58	5.47	7.33	6.93	7.09	15.80

Table 21. Statistical analysis of percent of total VMT at > 1,500 RPM of pilot sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	2.06	2.6404	2.94	3.57	3.95	1.07
N	6602	4431	5798	6636	5270	3527
SD	0.85	1.6895	1.05	1.46	1.67	1.51
t Test	N/A	-21.1709	-50.51	-72.76	-74.76	36.02
Significant Difference (0.05)	N/A	Yes	Yes	Yes	Yes	Yes

Table 22. Statistical analysis of percent of total VMT at > 1,500 RPM of control sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	2.48	3.42	3.95	4.53	4.83	4.48

Table 23. Comparison of percent of miles driven at > 1,500 RPM of pilot, control day cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (*X*)	15.80	6.76
N	460	1122
SD	7.32	4.01
t Test	N/A	24.99
Significant Difference (0.05)	N/A	Yes

Table 24. Comparison of percent of miles driven at > 1,500 RPM of pilot, control sleeper cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (*X*)	4.48	1.07
N	1742	3527
SD	0.91	1.51
t Test	N/A	101.86
Significant Difference (0.05)	N/A	Yes

4.2.4 Fuel Economy

Fuel economy is one of the most common metrics for evaluating fuel-efficient driving. The study team used the fuel-monitoring system to collect data on fuel consumption and miles traveled. The formulation for average fuel economy used in this study is the VMT divided by the gallons of fuel consumed for the trip on a 30-minute basis. The team excluded any fuel consumed when a truck was idling from the fuel consumption calculation, as the study focus was strictly based on VMT.

Figure 13 and Figure 14 provide plots for day cab groups and sleeper cab groups, respectively, for fuel economy as a function of time during the 2010–11 study period. The fuel economy trend improves over time in both vehicle groups as the study progresses from Stage 1 (baseline period—November and December) through the successive, more involved driver interventions to Stage 5 (July and August). Note that in Stages 2–5, neither any feedback nor any coaching was provided to drivers specifically on fuel economy; however, in Stage 5, rewards were provided to drivers specifically on fuel economy. The trend line is positive with an R^2 value of approximately 0.9.

Data shown in Table 25 and Table 27 illustrate that both the pilot day and the pilot sleeper groups, respectively, experienced significant benefits from the intervention process. Pilot day cab drivers had an average of 7.77 mi/gal at Stage 5 compared with a baseline of 7.07 mi/gal—a 9.3 percent increase in fuel economy as calculated from the data presented in Table 25. Pilot sleeper cab drivers had an average of 7.42 mi/gal at Stage 5 compared with a baseline of 7.04 mi/gal—a 5.4 percent increase in fuel economy as calculated from the data presented in Table 27. When both the pilot and the control groups at Stage 5 are compared (Table 29 and Table 30), there are three conclusions: 1) the difference in fuel economy between the control day cab and the pilot day cab groups is statistically significant, 2) the difference in fuel economy between the control sleeper cab and the pilot sleeper cab groups is statistically significant, and 3) sleeper cabs had the higher fuel economy gain of 9.8 percent compared to 6.6 percent for day cabs.

In general, the overall intervention process dramatically improved fuel economy throughout the process, particularly during Stage 4—when drivers received coaching relating to safety—and during Stage 5—when drivers were coached for only safety and rewarded for both safety improvements and fuel economy improvements. The trends in fuel economy improvements in the pilot sleeper cab and the pilot day cab groups continued during the nonintervention period.

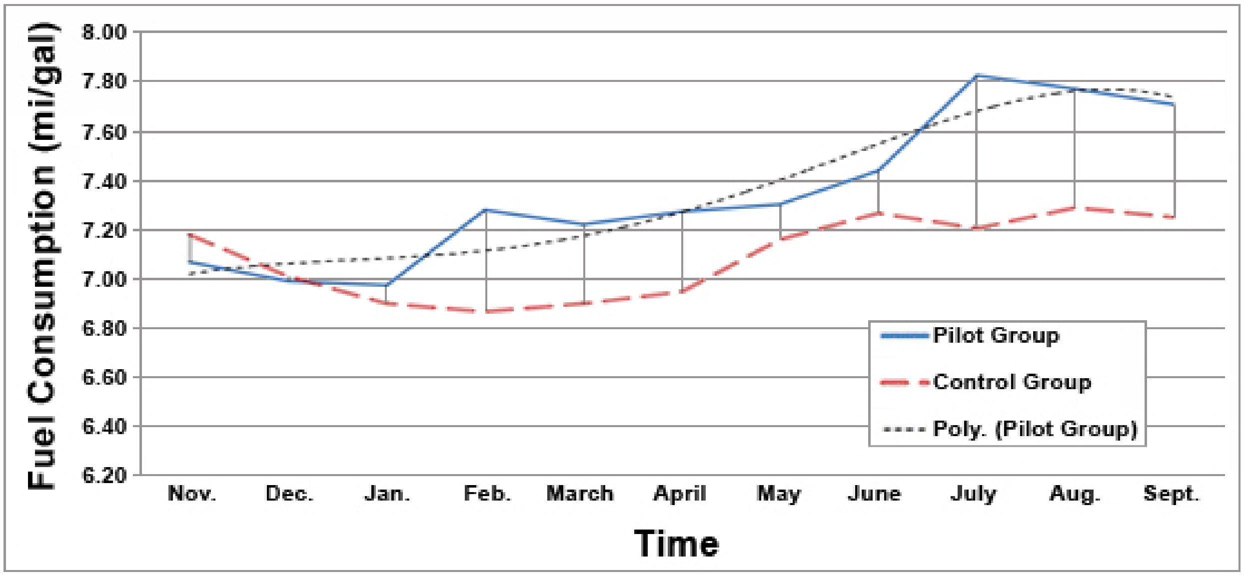

Figure 13. Line graph. Average fuel economy of day cab group.

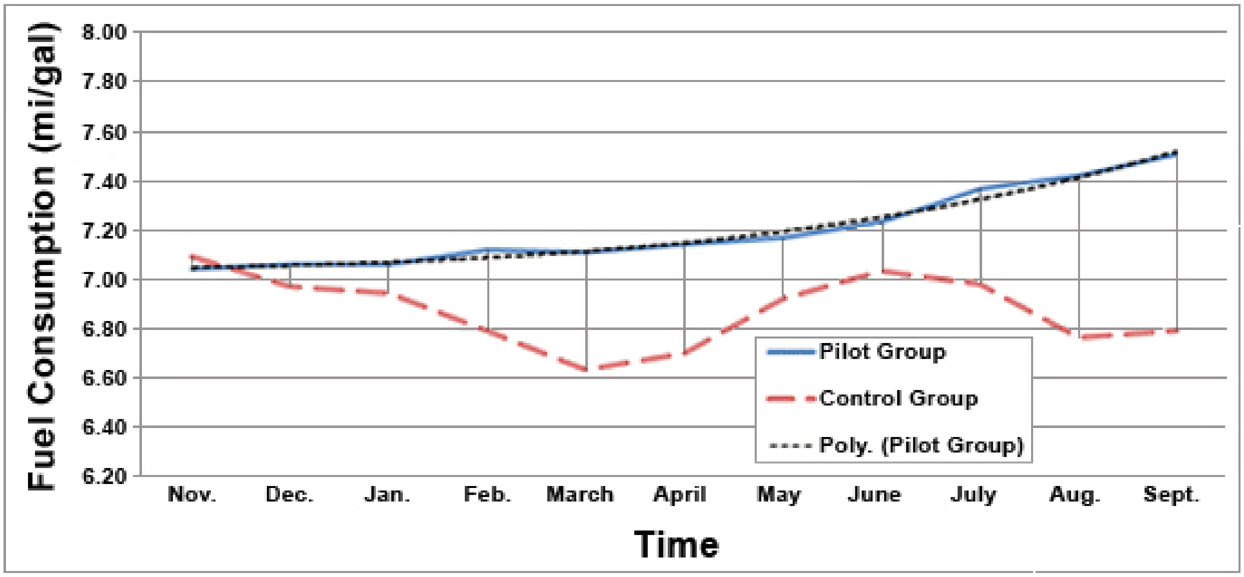

Figure 14. Line graph. Average fuel economy of sleeper cab group.

Table 25. Statistical analysis of average fuel economy (mi/gal) of pilot day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (*X*)	7.07	6.99	7.22	7.30	7.44	7.77
N	1221	683	305	417	638	580
SD	1.04	1.05	1.02	1.11	1.11	1.07
z Test		1.38	2.53	3.99	7.47	13.22
Significant Difference (0.05)	N/A	No	Yes	Yes	Yes	Yes

Table 26. Average fuel economy (mi/gal) of control day cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (X)	7.18	7.01	6.90	7.16	7.27	7.29

Table 27. Statistical analysis of average fuel economy (mi/gal) of pilot sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (X)	7.04	7.0596	7.11	7.17	7.23	7.42
N	2832	6708	2619	3236	2898	1647
SD	0.88	0.9733	1.02	1.06	1.07	1.08
z Test	N/A	0.1176	1.61	4.45	6.51	12.13
Significant Difference (0.05)	N/A	No	No	Yes	Yes	Yes

Table 28. Average fuel economy (mi/gal) of control sleeper cab group.

Variable	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4	Stage 5
Average (X)	7.09	6.97	6.63	6.92	7.03	6.76

Table 29. Comparison of average fuel economy (mi/gal) of pilot and control day cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (X)	7.29	7.77
N	471	580
SD	1.25	1.07
z Test		6.22
Significant Difference (0.05)	N/A	Yes

Table 30. Comparison of average fuel economy (mi/gal) of pilot and control sleeper cab groups at Stage 5.

Variable	Stage 5 Control	Stage 5 Pilot
Average (X)	6.76	7.42
N	1569	1647
SD	0.59	1.08
z Test	N/A	17.99
Significant Difference (0.05)	N/A	Yes

Following Stage 5, as Figure 15 shows, the pilot day cab group fuel economy increase levels off at approximately 7.8 mi/gal. However, the pilot sleeper cab group continues to demonstrate further improvement in fuel economy, attaining 7.5 mi/gal. Thus, the impact of the driver intervention process appears to continue to have a positive effect on fuel economy even when the intervention period (Stage 5) has ceased at the end of August. Note also that the fuel economy for either the pilot day or the pilot sleeper cab group did not revert to the pre-intervention stage (November and December).

In addition, the pilot data appear to illustrate that fuel economy correlates with safe driving, assuming that safe driving can be represented by minimizing unsafe events and unsafe events can be represented by sudden accelerations and decelerations. Because the trends on fuel economy

(Figure 13 and Table 25 and Table 29) increase as the trends on unsafe (yellow and red) events (Figure 5 and Figure 7 and Table 5 and Table 9) decrease all for the same set of drivers (namely, pilot day cab drivers), the trends are negatively correlated. For simplicity, Figure 5, Figure 7, and Figure 13 have been combined and placed on the same plot, Figure 15, to enable the reader to visualize the negative correlation between the trends between fuel economy and unsafe events for pilot day cab driver performance. Therefore, improved fuel economy can be said to be correlated with safer driving. It could be suggested—though it has not been proven—that safer driving by pilot day cab drivers causes improved fuel economy because the feedback and coaching in the intervention process was provided to the drivers for safety only—not for fuel economy. Therefore, any improvements in fuel economy for the pilot day cab drivers would presumably be linked to safer driving.

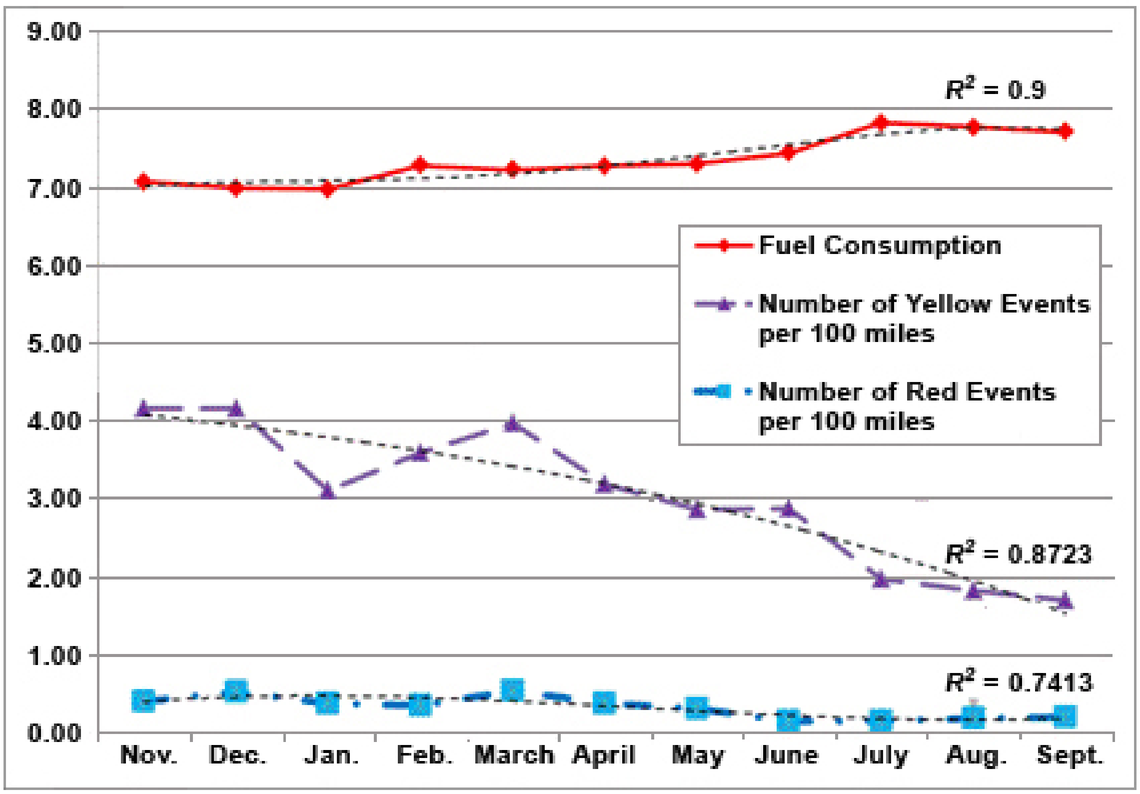

Figure 15. Line graph. Comparison of trend in yellow events, red events, and fuel consumption (mi/gal) for drivers of pilot day cabs.

Similarly, because the trends on fuel economy (Figure 14, Table 27, and Table 30) increase as the trends on unsafe (yellow and red) events decrease (Figure 6, Figure 8, Table 7, and Table 11) all for the same set of drivers (namely, pilot sleeper cab drivers), the trends are negatively correlated. Figure 6, Figure 8, and Figure 14 have been combined and placed on the same plot, Figure 16, to enable the reader to visualize the negative correlation between the trends between fuel economy and unsafe events for pilot sleeper cab driver performance. Therefore, fuel economy can be said to be correlated with safer driving.

In other words, improvement in safe driving appears to be correlated with improvement in fuel economy. It could be suggested—though it has not been proven—that safer driving by pilot sleeper cab drivers causes improved fuel economy because the feedback and coaching in the intervention process was provided to the drivers for safety only—not for fuel economy. Therefore, any improvements in fuel economy for the pilot sleeper cab drivers would presumably be linked to safer driving.

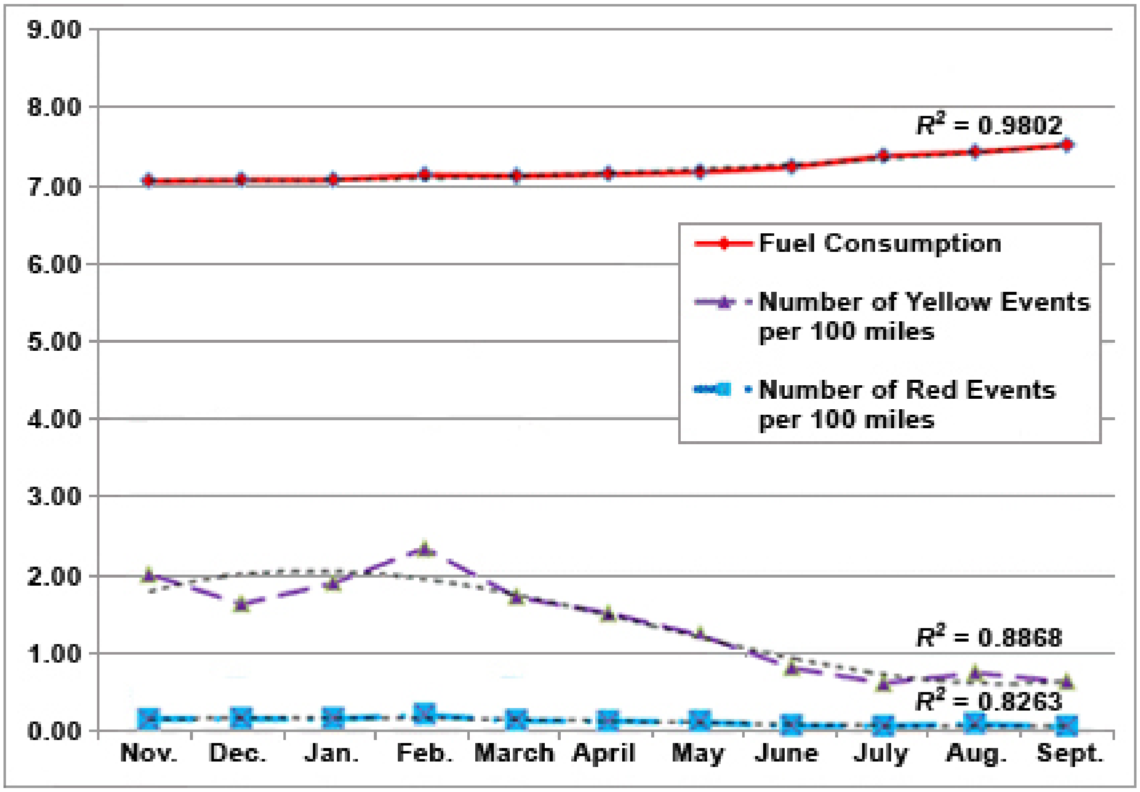

Figure 16. Line graph. Comparison of trends in yellow events, red events, and fuel consumption (mi/gal) for drivers of pilot sleeper cabs.

The team believes that to understand these trends better and to assess their full impacts, the study period should be extended over a period spanning 36–60 months. This will allow for multiple time periods and a larger sample size. This will allow also for collection of crash data, which are more definitive of safe driving than the proxies used in this study. The reader should recognize these limitations in the data presented.

5. GENERAL DISCUSSION

Improving fuel economy in trucks depends on many factors, including driver behavior, vehicle characteristics, tires, environment, operations, and maintenance. The study found that employing simple measures to monitor key performance parameters and providing driver intervention through coaching and low-cost incentive programs (such as gift cards) can translate into significant fuel-saving improvements. However, fleet managers can easily overlook technologies and intervention programs that can monitor driver behavior and correct unsafe events. Driver awareness, by itself, will not succeed in achieving change in driving behavior. Only a long-term, sustained coaching program, accompanied by targeted behavior-change initiatives will achieve a safe/fuel-efficient driving culture.

This section presents the major high-level conclusions of this research project.

- A telematics system was successfully demonstrated to be effective in improving motor carrier efficiency. In this field study, the research team demonstrated that telematics can be used successfully to monitor driver performance and improve safe and fuel-efficient driving behavior. Telematics also can provide in-cab feedback to alert the driver to unsafe driving events. When combined with driver intervention in the form of coaching and incentives, the results were safer driving and improved fuel economy.
- Telematics was used in this field study to monitor the following four specific performance parameters:
  - Unsafe events (sudden accelerations and decelerations) expressed as yellow events and red events, depending on event severity.
  - Speeding.
  - Engine RPM.
  - Fuel economy.
- The following are the major findings for each performance parameter measured across the pilot and the control groups:
  - Unsafe events (sudden accelerations and decelerations expressed as yellow events).
    - As the result of monitoring and intervention, the drivers of sleeper cab groups experienced around a 55-percent reduction in yellow events per 100 miles traveled between Stage 1 (baseline, pre-intervention stage) and Stage 5 (final stage, where feedback, coaching, and incentives were provided to the driver). The day cab group had a higher number of yellow events, approximately two events for every one sleeper cab yellow event.
    - During the winter months, weather can significantly reduce driving speeds in the northeast. Driving is more hazardous because of wet, snow-, and ice-covered roads. Figure 5 and Figure 6 illustrate a slight upward trend during this period, followed by significant decreases in these events. This is expected in part because of the geographic location of the fleet's operation.
  - Unsafe events (sudden accelerations and decelerations expressed as red events).

- As the result of monitoring and intervention, drivers of pilot day cabs experienced a 63-percent reduction in red events compared to drivers of pilot sleeper cabs who experienced a reduction of 47 percent between Stages 1 and 5; however, this reduction is not statistically significant. Pilot sleeper cab drivers experienced a reduction of 60 percent between Stages 1 and 4, which was statistically significant. The day cab group had a higher number of red events, averaging about three red events for every one sleeper cab red event.
- As shown in Figure 7 and Figure 8, Stage 4 (month of June) seems to have had the greatest benefit. The trend in reduction of red events continues beyond the termination of Stage 5 (beyond August).
- The results obtained are consistent with the literature. Aggressive driving is expected to increase fuel consumption and can use as much as 0.5 gallons of fuel during a single event.[6,18] Driving without harsh accelerations, hard braking, and sudden lane changes can lead to substantial reductions in fuel consumption, which also can reduce vehicle operating and maintenance costs.[19]

– Speeding.
  - Overall, sleeper cab drivers (long-haul drivers) have the most to gain from monitoring and intervention in order to reduce percent of total miles driven at more than 65 mi/h. In a comparison between the pre-intervention baseline (Stage 1) and the last driver intervention stage (Stage 5), pilot sleeper cab drivers showed a 42-percent reduction in percent of miles driven at > 65 mi/h compared to a 32-percent reduction for pilot day cab drivers.
  - During the winter months, driving in the northeast can result in reduced driving speeds as manifest in the significant dips in the plots for all driver groups shown in Figure 9 and Figure 10.
  - At Stage 3 (May) when feedback was provided on speeding (via blinking green lights in the in-cab display), a much more significant drop occurs for the average percent of total miles driven at > 65 mi/h starts to appear for the pilot day cab group (Table 13) than for the pilot sleeper cab group (Table 15).
  - As shown in Figure 9 and Figure 10, Stage 5 (July) seems to have had the greatest benefit. The reduction in speeding continues beyond the project termination at Stage 5 (approximately August) and does not return to the baseline (Stage 1, which occurs in the months of November and December) level.

– Engine RPM.
  - Overall, sleeper cab drivers (long-haul drivers) have the most to gain from monitoring and intervention in terms of reduced percent of total miles driven at > 1,500 RPM. In a comparison between the pre-intervention baseline (Stage 1) and the last driver intervention stage (Stage 5), pilot sleeper cab drivers showed a 48-percent reduction compared to a 27-percent increase for pilot day cab drivers.
  - Day cab drivers in both the pilot and the control groups display the same trend up to the end of Stage 3 (May); however, during Stage 4 (late June), the line for the pilot day cab drivers dips below the line for the control day cab drivers (as seen in Figure 11).

- › As shown in Figure 11 and Figure 12, the reduction in percent of miles driven at > 1,500 RPM continues beyond the termination of Stage 5 (beyond August) and even beyond the period of no intervention (beyond September) and does not return to the baseline level (Stage 1, November and December).
- › Even though no feedback, no coaching, and no incentives were provided to drivers of both pilot day cabs and sleeper cabs to improve the percent of miles driven < 1,500 RPM, the focus of the intervention process on reducing yellow and red events seems to have had an indirect effect on reducing excessive RPM in both pilot groups.

– Fuel Economy.
  - › In a comparison between the pre-intervention baseline (Stage 1) and the last driver intervention stage (Stage 5), drivers of pilot sleeper cabs showed a 5.4-percent gain in fuel economy compared to a 9.3-percent gain in fuel economy for drivers of pilot day cabs.
  - › As shown in Figure 13 and Figure 14, Stage 5 (July) seems to have provided the greatest benefit; the gain in fuel economy continues beyond the termination of Stage 5 (beyond August) and does not return to the baseline level (Stage 1, November and December).

– The trends in Figure 15 appear to illustrate that fuel economy correlates with safe driving if safe driving can be assumed as the minimization of unsafe events, and unsafe events can be assumed to be represented by sudden accelerations and decelerations. Because the trends on fuel economy increase as the trends on unsafe (yellow and red) events decrease, all for the same set of drivers (namely, day cab drivers), the trends are negatively correlated. In other words, improved fuel economy can be said to be correlated with safer driving.
  - › Similarly in Figure 12, because the trends on fuel economy increase as the trends on unsafe (yellow and red) events decrease, all for the same set of drivers (namely, sleeper cab drivers), the trends are negatively correlated. In other words, fuel economy can be said to be correlated with safer driving.

– While not proven, it can be suggested that safer driving is associated with improved fuel economy because the coaching in the intervention process was provided to the drivers for safety only—not for RPM, or fuel economy. The effect of driving safer was less speeding, less driving at excessive RPM, and improved fuel economy.

– Because safe driving can be said to conserve fuel, and conserving fuel reduces emissions, safe driving can also be said to reduce emissions. One gallon of diesel produces about 22.2 pounds of CO_2; thus, every gallon of diesel saved reduces 22.2 pounds of CO_2.

– Fuel costs account for 28–38 percent of the truck fleet operating costs(3) and the 6–8-percent savings in fuel consumed, as realized in this study, will increase the fleet profitability. For a medium-sized fleet of 1,000 Class 8 vehicles, the increase in profitability based on a modest 6-percent reduction in fuel consumption can be as much as $4.5 million dollars annually at current fuel prices. Further, the other benefits that accrue because of improved driving habits are not quantified in this study but potentially can reduce costs associated with vehicle maintenance, insurance, and possibly traffic violations and vehicular crashes.

- Stage 5 (incentives) of the driver intervention process did not appear to have any major increase or additional benefits in reducing frequency of yellow events and red events, reducing driving at speeds > 65 mi/h and > 1,500 RPM, and improving fuel economy. Post-intervention data collection indicate that the trends in reducing frequency of yellow and red events, reducing percent of miles driven at speeds > 65 mi/h and > 1,500 RPM, and improving fuel economy continued, and drivers did not revert to pre-intervention period behaviors.

5.1 RECOMMENDATIONS

Key recommendations are as follows:

- Vendors should be encouraged to develop and market telematics technologies that monitor key safety and fuel economy performance variables. Telematics systems must be able to generate daily updates on driver performance (versus truck performance), as well as summary statistics on the fleet customized to the respective audiences, including fleet managers, driver, and executives. This data must be made available beyond the vendor Web site and emailed to the client place of operation. The key to a successful safety/fuel efficiency culture is easy access to data that is available immediately for use and customized to the respective audience.
- The importance of establishing a new safety/fuel efficiency culture should be recognized among truck fleets. Fleet managers must be exposed to training prior to communicating feedback or providing coaching to drivers on safety and fuel economy.
- Documentation that focuses on a safety/fuel efficiency culture and that specifically targets the various stakeholders (fleet executives, fleet managers, and drivers) should be developed.
- Federal agencies should provide guidance and resources to advance a safety/fuel-efficiency culture. The motor carrier fleets must champion this new safety/fuel efficiency-culture program for the trucking industry.
- Additional research is recommended to further investigate the study findings over a longer period (36–60 months). The rationale is that a longer period allows for collection of crash data, which are more definitive measures of safe driving. Because this study was limited in scope, the study team was not able to collect sufficient data to analyze crashes, and instead, examined proxies for safety, such as unsafe events (i.e., sudden accelerations, hard braking, and sudden lane changes).
- It is recommended that a similar study of telematics systems be completed with motorcoach drivers.

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