Transport Policy 53 (2017) 161–174

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

An exploratory study of hours of service and its safety impact on motorists

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ARTICLE INFO

Keywords:
Federal Motor Safety Carrier Administration (FMSCA) hours of service (HOS)
Commercial motor vehicle (CMV) fatigue regulation
Truck driver safety
34-hour restart
Parametric and non-parametric

ABSTRACT

There were an estimated 438,000 truck crashes in 2014 that led to approximately 110,000 injuries and 3903 deaths (HTSA and DoT, 2014). Truck driver fatigue has been cited as a major reason for these accidents Federal Motor Carrier Safety & Administration, 2015 (). In July 2013, the Federal Motor Carrier Safety Association (FMCSA) revised its hours of service (HOS) regulatory policy, which restricts the number of duty and driving hours a truck driver can operate in order to reduce the fatigue related accidents involving trucks. The revision changed the unlimited restart (allows truck drivers to reset their duty time log back to zero) provision by restricting it to 1 restart per 168 h (1 week) and added that the restart must span two consecutive 1 a.m. to 5 a.m. periods. Lawmakers suspended these two aspects of the restart provision in the Consolidated and Further Continuing Appropriations act on December 16, 2014 until more analysis was completed on the efficacy of these regulations due to unintended consequences that allegedly negatively affected motorist's safety. Countering truck driver fatigue is an important issue and an extremely difficult task because of the many confounding aspects that can cause fatigue. The new regulation set forth in July 2013, was supposed to lessen fatigue and thus reduce accidents caused by truck drivers. The current HOS regulation was in place for approximately 16 months, producing enough data for a statistical analysis of its effects on truck driver safety. This research found that by comparing truck driving safety data prior to the change in July of 2013 (the unlimited restart provision) to truck driving safety data during the enactment of the 1 restart per 168-h restriction and 1 a.m. to 5 a.m. provision that the percent of accidents caused by truck drivers did not decrease. Furthermore, this research found that the HOS changes implemented on July 1, 2013 have not led to a significant change in accidents involved and caused by truck drivers. These results suggest that other factors appear to be linked to motorists' safety, rather than the updated HOS regulation.

1. Introduction

Trucks are used to haul goods more than any other mode of transportation. In fact, 73.1% of value and 71.3% of volume of US domestic goods are shipped by trucks (US Census Bureau, 2015). Trucks transport a large portion of US shipped goods, and truck drivers are responsible for a large number of crashes and fatalities. There were an estimated 438,000 truck crashes in 2014 that led to approximately 110,000 injuries and 3903 deaths (HTSA and DoT, 2014). Pritchard (2010) found that there are about 5000 fatal crashes involving trucks per year resulting in social costs greater than 32 billion dollars. Many of these accidents have been caused by fatigued truck drivers, which could have been prevented with proper rest and truck driver awareness (Quan et al., 2015). The Federal Motor Carrier Safety Administration (FMCSA) has instituted measures that restrict the driving and duty hours of truck drivers to promote safety and minimize any negative economic impact on the commercial motor vehicle industry.

FMCSA controls the duty and driving time limits of truck drivers through Hours of Service (HOS) regulations. HOS regulations restrict the number of hours a truck driver can operate in order to reduce fatigue related accidents. These regulations have changed over the years due to regulatory agencies attempting to balance fatigue related accidents and economic impact (see Table 1). In 2003, FMCSA introduced a restart provision to the HOS regulations, which allowed truck drivers to reset their duty time log back to zero as long as they took 34 consecutive hours off duty. For example, if a driver has 5 consecutive 14-h duty days (70-h in 8-days) he/she cannot drive until the 9th day, unless a restart is accomplished. A restart resets the 8-d clock back to zero after the requirements are met, which would allow the driver to possibly drive again on the seventh day. In 2013, FMCSA altered the restart provision, which changed the amount of restarts from unlimited to 1 restart per 168-h and included that the 34 cumulative hours off must also occur over two consecutive 1 a.m. to 5 a.m. periods.

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http://dx.doi.org/10.1016/j.tranpol.2016.10.001
Received 13 July 2015; Received in revised form 22 July 2016; Accepted 7 October 2016
Available online 02 November 2016
0967-070X/ Published by Elsevier Ltd.

Table 1
History of Hours of Service changes.

Year changed	1938	1939	1962	2003	2005	2013	2014
Driving Hours	**12**	**10**	10	**11**	11	11	11
On-Duty Hours	**15**	**N/A**	N/A	**14**	14	14	14
Off-Duty Hours	**9**	**8**	8	**10**	10	10	10
Max Daily Work	**12**	**N/A**	N/A	N/A	N/A	N/A	N/A
Duty Cycle	**24**	24	**N/A**	N/A	N/A	N/A	N/A
60 h (7-d)	**60**	60	60	60	60	60	60
70 h (8-d)	**70**	70	70	70	70	70	70
Break						**≥8**	≥8
Restart				**≥34**	≥34	≥34	≥34
Number of Restarts						**1 Per 168 h**	**N/A**
1 a.m. to 5 a.m.						**≥2**	**N/A**
Sleeper berths split sleep				**≥2 h**	**≥8 h**	≥8 h	≥8 h
Changes	7	4	1	5	1	3	2

Bold indicates change from previous year.

There have been conflicting claims about the effectiveness of these recent HOS regulation changes. Some trucking unions and some members of Congress have claimed negative safety implications due to prolonged traffic congestion during daytime hours and increased fatigue (Ferro, 2014; Short, 2013). Conversely, legislative branch members and research has claimed that the HOS revision has decreased accidents, reduced damage, and most importantly, saved lives(G. X. Chen et al., 2015; Federal Motor Carrier Safety Administration, 2010; Ferro, 2014)). Some research has also shown that more congestion increases the number of accidents by trucks (due to the disparity between truck's and car's acceleration and deceleration times) but lessens the severity (due to overall slower speeds) (Tay and Rifaat, 2007; Zhu and Srinivasan, 2011).

Although it is clear that driver fatigue is dangerous and has been linked to higher accident rates (Dinges, 1995; Mackie and Miller, 1978; Summala and Mikkola, 1994; Williamson and Friswell, 2013; Zhu and Srinivasan, 2011), the effectiveness of HOS regulatory policy on reducing fatigue and making roads safer is still unclear (Arnold et al., 1997; Min, 2009b). Research has found that many drivers actually begin their driving periods fatigued, indicating that HOS may restrict the number of operating hours but does not directly reduce fatigue or ensure alert truck drivers (Abrams et al., 1997).

More specifically, these two restart changes (1 restart per 168 h restriction and the 1 a.m. to 5 a.m. provision) that have been suspended, until more research is conducted, are believed by some to increase accident rates due to shifting truck drivers operational times to more congested periods (Federal Motor Carrier Safety Administration, 2011; Ferro, 2014; Short and Murray, 2014). Congress was set to reevaluate these two suspended restart changes, on September 30th of 2015 or after FMCSA finishes their studies revealing the HOS 1 per 168-h restart and 1 a.m. to 5 a.m. provision efficacy.

This research investigates the safety efficacy of the 1 restart per 168-h restriction and 1 a.m. to 5 a.m. provision that was enacted in July of 2013 through parametric and non-parametric statistical analysis on accidents involving trucks within the state of Ohio. This research analyzes Ohio's accident data involving truck drivers and extrapolates these findings to the US as a whole. This research compares the accidents involving trucks over two-time periods: 1) July 2009 to July 2013 – a period prior to the increase in restart restrictions and 2) July 2013 to July 2014 – a period in which the 1 restart per 168-h restriction and 1 a.m. to 5 a.m. provision were in place. Since these are the main aspects of HOS regulations that changed between these two-time periods, this research aims to discover how the restart changes affected truck drivers and their accident rate in Ohio.

The regulatory policy levied on the trucking industry has significant managerial, governance, and societal implications that may change driving safety for motorists. This research first details the history of HOS and briefly discusses the most recent changes to HOS. Then the methodology section provides the details of the analysis that was performed using the Ohio data followed by a discussion of the relevant findings. Finally, some concluding remarks and suggestions for future research are presented.

2. Literature review

2.1. Hours of Service (HOS) background

Federal Motor Carrier Safety Association (FMCSA) establishes HOS regulations for truck drivers. These regulations stipulate the maximum duty and driving hours of truck drivers. Moreover, HOS rules limit both daily and weekly duty and driving hours of truck drivers. Government agencies have stated that regulation in the trucking industry is important because of the increased potential of an accident that occurs as truck drivers work long hours (Federal Motor Carrier Safety & Administration, 2015). Previous research has also filled gaps regarding the source of truck driver accidents. Most of this research has measured the effects of singular restrictions and accidents involving trucks with respect to fatigue, some examples of effects include: multi-day driving patterns (Kaneko and Jovanis, 1992), starting fatigue level (Crum and Morrow, 2002), driving hours per day (Hanowski et al., 2009; Soccolich et al., 2013; Williamson et al., 2011), driving time of day (Blower and Campbell, 1998), breaks (Chen and Xie, 2014a), sleeper-berths (Hertz, 1988), truck miles (Joshua and Garber, 1990; Jovanis and Chang, 1986; Lyman and Braver, 2003), truck driver health (Anderson et al., 2012; Stoohs et al., 1994), and regulation enforcement improvements due to Electronic On-Board Recorders (Cantor et al., 2009).

These research efforts and others have been influential in changes that have been made to HOS regulations. The following section provides a historical perspective of some of these HOS changes.

2.2. History of Hours of Service

In an effort to mitigate fatigue-related accidents involving long-haul truck drivers, the Interstate Commerce Commission (ICC) established HOS regulation in 1938 ("Federal Register, Volume 65 Issue 85", 2000). By 1939, regulations restricted truck driving to ten-hour increments and mandated rest periods of eight hours between those increments ("Federal Register, Volume 65 Issue 85", 2000). The policy was controversial for some drivers and government officials. A FMCSA (2000) report quotes an ICC official who objected to the proposed HOS regulation in 1937:

> We have no control over the manner in which a driver may spend his time off-duty, although some of his spare time activities may tire him as much as any work would do. We can only emphasize, by this comment, the responsibility which is the driver's own to assure himself of adequate rest and sleep, in the time available for this purpose, to ensure safety of his driving, and likewise the employer's responsibility to see that his drivers report for work in fit condition (ICC, 1937).

The HOS policy remained predominantly unchanged for the next 60 years (Hall and Mukherjee, 2008). Subsequent revisions to the policy, which were implemented in January of 2004, made three main changes with respect to time: 1) driving time increased to 11 h increments, 2) duty hour restriction changed to a maximum of 14 h on-duty and 10 h off-duty before coming on-duty again, and 3) provided a 34-h restart period (Federal Motor Carrier Safety Administration, 2016). These revisions occurred because there was "general recognition that the existing rules for the truck industries had been well implemented before there had been a clear scientific understanding of fatigue causal factors (e.g., time of day, amount and timing of sleep, time awake, and time on task)" (Federal Motor Carrier Safety Administration, 2003, p. 22458). FMCSA brought in experts and relied heavily on fatigue research in order to update these HOS regulations.

2.3. History of the restart provision

The 34-h unlimited restart provision for all commercial motor vehicles was instituted in 2003 in order to reduce the effect of cumulative fatigue and prevent fatigue-related crashes. However, FMCSA later found that the 34-h unlimited restart provision provided the ability for truck drivers to attain more hours than 70 h per week, which was previously not possible because of the 70-h restriction. The restart enabled truck drivers to operate 5 days, on a maximum schedule, and take a restart on the 6th day and drive again on the 7th day, enabling truck drivers to attain approximately 82 h per 7-d period (Federal Motor Carrier Safety Administration, 2011). This prompted FMCSA to limit the restart provision.

Further restart limitations were implemented on July 1, 2013. The goal of the changed regulations was to lessen long work hours and decrease fatigue-related crashes and long-term health problems for truck drivers (Dingus et al., 2006; Federal Motor Carrier Safety Administration, 2003; Rodriguez et al., 2006). The additional restart restrictions included two main changes: 1) required that the restart restriction time spans from 1 a.m. to 5 a.m. for two consecutive nights, and 2) limiting to 1 restart per 168-h interval.

The additional restart restrictions were predicted to further reduce the number of accidents involving trucks, from the continuing downward trend in safety-related accidents, by preventing an additional 1400 crashes, 560 injuries, and 19 deaths per annum (Federal Motor Carrier Safety Administration, 2016). These two restart provisions were suspended due to growing concerns of unintended consequences in December of 2014 until September 2015, or until further research was accomplished providing data on the efficacy of these provisions. The 34-h unlimited restart provision was reconstituted in December of 2014.

2.4. 1 Restart per 168-h

One of the major aspects of the HOS regulations is the number of restarts a driver can utilize. In July 2013, the restart changed from unlimited to only one restart per 168-h period. The ability to take more than one restart per 168-h period provided drivers with the opportunity to be on duty more hours than the 60 h per 7 days provision or 70 h per 8 days provision. Using unlimited restarts, under the 60-h provision, a truck driver could obtain 78.4 duty hours per week. Under the 70-h provision, using unlimited restarts, a truck driver could obtain 81.66 duty hours per week. The updated HOS regulation, which limits a driver to one restart per 168-h period, decreases the total number of duty hours to 70 for the 70-h provision and to 60 for the 60-h provision. This is approximately a 16.6% reduction for the 70-h provision, and a 30% reduction for the 60-h provision.

While more total duty hours within a given driving period has been shown to lead to more accidents (Cantor et al., 2010; Harris, 1977; Soccolich et al., 2013; Wiegand et al., 2009), no studies have been done on the safety implications of multiple restart periods and its effect on truck driver fatigue. Since drivers should be the most rested immediately following a restart period, assuming that more restarts during a given period may actually increase driver safety. However, FMCSA limited the restarts to 1 per 168 h because of excessive buildup of on-duty hours that can occur before and after a restart is taken, without completing the requested studies by congress regarding fatigue and use of multiple restarts (Federal Motor Carrier Safety Administration, 2011; Ferro, 2014).

2.5. 1 a.m. to 5 a.m. provision

In conjunction with the 1 restart per 168-h restriction, FMCSA instituted the 1 a.m. to 5 a.m. provision. Previous iterations of the HOS regulation have restricted the amount of driving and duty time for a truck driver, but regulations have never stipulated the exact time of day during which the restart time must occur (Federal Motor Carrier Safety Administration, 2016).

The 1 a.m. to 5 a.m. provision was adopted by FMCSA due to research indicating that the most effective sleep occurs at 2 a.m. to 5 a.m., thus ensuring time off during the major circadian low for the majority of truck drivers (Dongen and Dinges, 2005; Folkard and Tucker, 2003). Research has also found that sleep at night for daytime workers is better than sleep during the day for nighttime workers (Lavie, 1986; McCartt et al., 2000; Van Dongen and Mollicone, 2014).

By implementing the 1 a.m. to 5 a.m. provision, truck drivers who drive at night may also switch schedules and begin driving during the day to correspond with the time of the provision. This may improve safety, because research has found that when removing traffic density or congestion, driving at night is 10 times as dangerous than during the day for truck drivers (Horne and Reyner, 1995; Lavie, 1986). Although nighttime driving is dangerous due to potential for increased fatigue and darkness, daytime driving is dangerous due to increased congestion.

Shifting more drivers to the day leads to increased congestion, which has been shown to impact motorist's safety. First, increased congestion reduces miles driven, thereby making drivers operate more daily hours (Kok et al., 2012) and exposing the driver's to the higher risks associated with longer days. Second, research has shown that traffic flow was the single most important factor (more than circadian rhythm) in determining accident rates (Dingus et al., 2006). Higher disparity of speed differences between vehicle types is a major reason for increased accident rates, due to the acceleration and deceleration differences between large and small vehicles in congestion (Beilock, 1995; Chen et al., 2011; McCorry and Murray, 1993; Neeley and Richardson, 2009; Peeta et al., 2005). Basically, as congestion increases the rate of accidents also increases (Kononov et al., 2008). Campbell (1995) suggested providing greater incentives for truck drivers to operate outside the congested periods due to increased safety for trucks and motorists. However, FMCSA's 1 a.m. to 5 a.m. provision resulted in an incentive to the drive during congested periods (Commerce Appropriations Act, 2014).

One of the other possible consequences of the 1 a.m. to 5 a.m. was that nighttime drivers may shift their schedule to minimize the restart period duration and increase operating hours (Federal Motor Carrier Safety Administration, 2011; Short and Murray, 2014). FMCSA also stated that nighttime drivers will generally migrate to daytime schedules due to family life and events occurring at home since they do not want to sleep when everyone else is awake (Federal Motor Carrier Safety Administration, 2011). Shifting schedules has been found to be a major cause of truck driver fatigue (Åkerstedt et al., 2008; Dongen and Dinges, 2005; Rio-Bermudez et al., 2014; Williamson et al., 2011).

The 1 a.m. to 5 a.m. stipulation also becomes challenging because of the different and numerous time zones in which truck drivers operate. The restart period time is based on the truck driver's home terminal time and not their current location(Federal Motor Carrier Safety Administration, 2016). For example, a truck driver from Indiana driving to Nevada is mandated to rest during the restart period from the Nevada local time of 10 p.m. to 2 a.m. Conversely, a truck driver from Nevada driving to Indiana is mandated to rest during the restart period from the Indiana local time of 4 a.m. to 8 a.m., which may no longer span the most effective sleep time (2 a.m. to 5 a.m.). The 1 a.m. to 5 a.m. stipulation becomes even more arbitrary for truck drivers who are away from their home terminal time for long periods. Also, tracking home terminal times and local times, especially when crossing multiple time zones, becomes onerous for the truck driver and becomes the source of potential, accidental record keeping violations.

The safety impact of the 1 restart per 168 h and the 1 a.m. to 5 a.m. provision to truck drivers is difficult to discern because of the multiple effects that are occurring that were previously discussed: a likely increase in truck traffic during congested period, changes in truck driver circadian rhythm, a possible decrease in driving hours and night-time driving, and an unknown safety implications of the 1 am to 5 am home terminal time. FMCSA adopted the 1 restart per 168-h restriction and the 1 a.m. to 5 a.m. provision prior to completing some of the required congressional studies, which may have aided in understanding the possible safety implications of changing HOS regulations. Representative Richard Hanna (Vice Chair for Highways and Transit) stated "The intent is clearly that the study be completed before the rule is enacted," at which time the study was anticipated to be completed approximately one year after the change was ratified (Ferro, 2014).

2.6. Mandated 30-min break provision

The 30-min rest break is an additional HOS regulation that was adopted in July of 2013. The 30-min break was not suspended in December of 2014, and the break continues to remain in effect. Although the schedule placement of the 30-min break has some flexibility, it must occur within the first 8 h of driving. In order to count as a 30-min break, the truck driver must not be working in any capacity, but can use that time for such things as eating, resting, or exercising (Federal Motor Carrier Safety Administration, 2016).

Blanco et al. (2011) researched rest breaks, as part of a FMCSA-sponsored study, providing the legislative branch the conclusions needed to enact the 30-min break provision. They noted that of the 97 drivers monitored, their duty day was comprised of 66% driving, 23% non-driving work, and 11% resting. They also found that the rate of accidents decreased immediately following the break. However, they also observed that the rate of accidents were highest at the end of the driving period. Some research suggests that the addition of the break, which causes the overall duty day to be lengthened, may lead to more net accidents (Chen and Xie, 2014b; Short, 2013). This suggests that some of the benefits of the break are offset by an increase in accidents due to the extension of the driving period.

Another finding that challenges the 30-min break provision is the ability to enforce this regulation (Short, 2013). This rule ensures that the truck is not continually driven, due to the electronic logbook, but it cannot guarantee that the driver is not performing duty-related activities. Blanco et al. (2011) found that off-duty breaks were best, but any break that was different from driving also provided an accident rate reduction.

2.7. Unintended consequences of regulatory policy

Balancing many unique work and lifestyle demands makes a "one-size-fits-all" approach to regulation difficult. When policies are made in order to curtail a dangerous event or certain behavior, other unintended problems may arise. Senator Collins stated, "it has become clear that the rules have had unintended consequences that are not in the best interest of carriers, shippers and the public" (Patton, 2014).

Sometimes regulations intending to reduce fatigue may actually increase it for some truck drivers. A 2008 report to FMSCA found no evidence suggesting a 2003 rule change decreased the number of deaths caused by large truck crashes and stated that it may have actually increased the number of deathsFederal Motor Carrier Safety Administration, 2015; Short, 2013; Min, 2009; Holcomb, 2014). Simply put, HOS regulation does not ensure well-rested drivers; it ensures specified off-duty times and driving/duty time limits.

There are three unintended consequences of HOS: 1) a switching from nighttime driving to daytime driving, 2) an increase in the stress levels of drivers, and 3) a need for more truck drivers (Brewster and Short, 2014; Ferro, 2014; Goel, 2014; Short and Murray, 2014). Concerning switching schedules, FMSCA (2016) claimed to know of no reason why truck drivers would change from driving at night to driving during the day. This claim contradicts recent studies, which found approximately 15% of drivers have indeed changed their schedules by switching from nighttime to daytime driving in order to work within the regulations (Fender and Pierce, 2013). Changing work and sleep times have been shown to increase fatigue and the rate at which accidents occur (Åkerstedt, 1998; Goel, 2014; Rio-Bermudez et al., 2014; Torregroza-Vargas et al., 2014).

In addition to increasing fatigue, changing work and sleep times can increase physical, emotional, and mental stress levels for drivers (Chen et al., 2015; Sando et al., 2010). Truck drivers may also become fatigued from financial stress related to restrictive rules that are enforced by large ($2750 per incident) fines, or pay decreases due to driving time limitations (Federal Motor Carrier Safety Administration, 2016; Holcomb et al., 2014; Min, 2009a; Short, 2013).

The third unintended consequence of HOS is the need for more truck drivers. More restrictive HOS changes causes the loss of available man-hours, leading to an increased need for companies to hire more drivers and cancel or decline shipments (Min, 2009b). Newly hired drivers will not have the same experience or training as existing drivers. This may increase the rate at which truck drivers cause accidents (Belzer et al., 2014). HOS regulations create persistent driver training and retention challenges (Belzer et al., 2014). High turnover reduces driver qualifications and route familiarity, which in turn can decrease safety.

Although there are some negative unintended consequences of HOS regulations it is also important to note that HOS regulations may reduce the number of truck related accidents. This occurs by limiting the length of the duty and driving hours per day, mandate breaks during the driving period, and provide restart capabilities. Research has found that accidents occur when drivers are working long daily hours (Blanco et al., 2011; Jovanis et al., 2011; Saccomanno and Nassar, 1997; Soccolich et al., 2013), breaks reduce the number of accidents after the break (Blanco et al., 2011; Chen and Xie, 2014a), and that restart provision provide relief from cumulative fatigue (Dongen and Dinges, 2005; Gander et al., 2006; Van Dongen and Mollicone, 2014).

2.8. Accident background

Accidents per mile involving and caused by truck drivers have steadily decreased over time (Bruning, 1989; Lyman and Braver, 2003; Pritchard, 2010). In their final rule, FMCSA (2011) reported crash rates falling well before 2004 and a general downward trend in Commercial Motor Vehicle (CMV) deaths that rose between 2003 and 2006 and then dropped in the following years. FMCSA also reported there was another subsequent drop in driver deaths in 2008, but stated that it could be due to other factors such as a weaker economy that led to reduced driving, increased seat-belt use, and better training and retaining of truck drivers. In 1975, truck crashes occurred at a rate of 5.8 per billion miles traveled (Martinez, 1997) and is now at 1.27 per billion miles traveled (National Highway Traffic Safety Administration, 2016).

Although the overall number of accidents are declining per mile, there is research indicating the severity of accidents has increased due to size and speed of the trucks (Duncan et al., 1998; Zhu and Srinivasan, 2011). But severity of an accident has not necessarily led to a higher percentage of fatalities, which is in part due to safety technologies that benefit all motorists (Kahane, 2015). Safety technologies such as airbags (front and side), lane assist, LIDR, GPS, better maintenance of vehicles, and enhanced brakes are claimed to have saved over 328,551 lives from 1960 to 2002 (Kahane, 2015). In 2014, the NHTSA found that 1144 lives were saved among passenger vehicles in 2012 due to lane assist technologies. Drivers may also be receiving better training and awareness on factors leading to accidents such as fatigue, medication, weather conditions, traffic congestion, enabling higher quality risk-management decisions and thus a lower number of accidents caused by truck drivers.

There have been numerous studies approximating the percent of fatigue related truck accidents: 20% (Moonesinghe et al., 2003); 41% (The American Automobile Association Foundation for Traffic Safety, 1985); 31% (NTSB, 1990); 16 to 55% (Chang and Chien, 2013). In our research, the percent provided by a FMCSA sponsored study is used, which showed that fatigue is the main cause of truck-related accidents 13% of time (Craft & Blower, 2004).

2.9. Other changes in Ohio law

Other factors that may also have an impact on truck accidents during the periods studied are other changes to laws and regulations for vehicles in Ohio. There are two regulations that are thus discussed: speed limit changes and distracted driving laws implemented during the period studied (2009–2014). In the state of Ohio, House Bill 395 passed increasing speed limits for 607 miles of highways and freeways across Ohio, and also aligned truck speeds to the same speed as other motor vehicles (Grant, 2013). Studies have found increased crash rates and severity due to increased speeds; studies have also found large differences in speeds between vehicles correlate to higher crash rates (Aarts and Van Schagen, 2006; Solomon, 1964). However, Ohio increased speeds only on major roads. The speed limit increase in 2011 on the Ohio turnpike saw a decrease in the mean number of fatalities (Armon, 2013). The Crash Risk Curve, developed by Solomon (1964), illustrated that driving at the median speed had the lowest probability of a crash. Since truck drivers had lower speed limits than that of motorists, the speed variation on roads was greater and more unsafe. Since the bill both increased the speed limit for motorists on major roads (leading to an increase in crash rates) and uniformly aligned speeds for trucks and automobiles (resulting in a reduction in crash rates), it is reasonable to assume that the speed limit changes should not have significantly changed crash rates involving trucks over the periods being studied by this research.

The second law that changed dealt with distracted driving, which has been a major concern as a causal factor in crash accidents (Dingus et al., 2006; Young et al., 2007). Ohio passed a texting law in June 2012, which was primary for drivers under 18 and secondary (meaning that officers cannot cite based only on the texting) for drivers over 18. Since truck drivers must be over 21 to drive, and research has found that secondary texting laws do not have an effect on accident rate (Abouk and Adams, 2013) this law was not considered in this research.

The next section will discuss the approach used to discern the safety efficacy of the 1 restart per 168-h restriction and the 1 a.m. to 5 a.m. provision aspects of the recent HOS revisions on the safety of truck drivers in Ohio.

3. Method

Monthly data from all 88 counties in Ohio were analyzed, providing insight into the recent changes made to HOS regulation and the associated safety implications on motorist and truck driver safety. Monthly data was used because the changes to HOS occurred in July, instead of at the start of the calendar year, January. The state of Ohio data is primarily used because of its timely compilation of motor vehicle statistics available for research. The state of Ohio public safety office produces daily reports that enable data to be evaluated during the specified timeframe. The state of Ohio is used because it has a similar population density, roadways, and truck routes that cause Ohio (12.05 crashes per million people) and the average crashes in the US (11.22 crashes per million people) to also have a similar fatality rate with respect to large truck crashes (see Fig. 1).

Although Ohio's roadways or geography may be unique in the US, it does not present a problem in extrapolating Ohio's data because historical data captures any unique geography or roadway characteristics that may exist in Ohio. Also by analyzing the time in question (July 2013–June 2014) for Ohio and extrapolating upon that geographic data removes the element of change that may occur due to time (Gordon, 1994; Khasnabis and Ramiz-Al-Assar, 1989; Saccomanno and Nassar, 1997). Regressions are created from historical accidents involving trucks that occurred in Ohio providing a consistent historical percentage, which is used to approximate the impact of HOS in the US. Data used in Ohio provides information of HOS impact in the US similar to the extrapolating work conducted by Paddock (1974) and Vogt and Bared (1998) using road and intersection data from Minnesota and Washington to build accident models; and Khattak et al. (2003) who estimated risk factors in truck rollovers from police reports from North Carolina from 1996 to 1998.

A total of 60 months of retrospective data are analyzed. Since the HOS regulation was changed in July of 2013, calendar year data would not measure the correct treatments. The 12-month span from July 2013 to June of 2014 is named post-HOS data. In order to avoid seasonality fluctuations in the data, the other 48 months were grouped into four years starting in July and ending in the June (named pre-HOS data). This provides a total of five years of data that can be broken down by months, by year, and by pre- and post- HOS. Four of these five years, or 48 of the 60 months, detail accidents involving trucks regulated under the unlimited restart provision and 1 year, or 12 months, detail accidents involving trucks regulated under the 1 restart per 168-h restriction combined with the 1 a.m. to 5 a.m. provision.

There are nine variables of interest for each month. These variables are: 1) total fatalities involving trucks, 2) total fatalities caused by truck drivers, 3) percent of fatalities caused by truck drivers, 4) total injuries involving trucks, 5) total injuries caused by truck drivers, 6) percent of injuries caused by truck drivers, 7) total property damage accidents involving trucks, 8) total property damage accidents caused by truck drivers, and 9) percent of property damage accidents caused by trucks.[1] This research examined 540 data points from this 5 year or 60 month period (60 months *9 variables of interest =540 data points).

First pairwise comparisons were made between the pre- and post-HOS monthly outcomes of the nine variables of interest. More specifically, for the pre-HOS data, monthly data averages (4-months of data across four years for each calendar month), standard deviations, and variances were computed and compared to the same statistical measurements against the post-HOS monthly data using the paired *t*-test for injuries and property damage. For fatality data, parametric assumptions were not met to conduct the paired *t*-test, so the non-parametric Wilcoxon Signed Rank test was applied (Hollander et al., 2013).

In order to account for any possible downward trend of accidents over the years, these comparisons were expanded to examine the differences in the variables of interest by year versus grouping them as pre- and post-HOS. Each year was now considered a treatment in analysis of the variables of interest to capture differences utilizing parametric and non-parametric testing techniques.

To examine differences between years, Analysis of Variance (ANOVA) testing was conducted followed by the post-hoc Fisher's Least Significant Difference (LSD) pairwise comparison when ANOVA parametric assumptions were met. For the assumptions, normality was assessed using the Shapiro-Wilks test (Razali and Wah, 2011). Constant variance was assessed using the Bartlett test (Levene, 1960); and independence was assessed via the Durbin-Watson test (Kanlayasiri and Boonmung, 2007). Consequently, ANOVA was appropriate for analyzing injuries and property damage involving trucks or caused by trucks. Since the fatality data failed the test for normality, the nonparametric Friedman, Kruskal-Wallis, and subsequent post-hoc Wilcoxon Rank Sum tests were used for data relating to fatalities

[1] The investigating officer at the scene determined accidents caused by truck drivers.

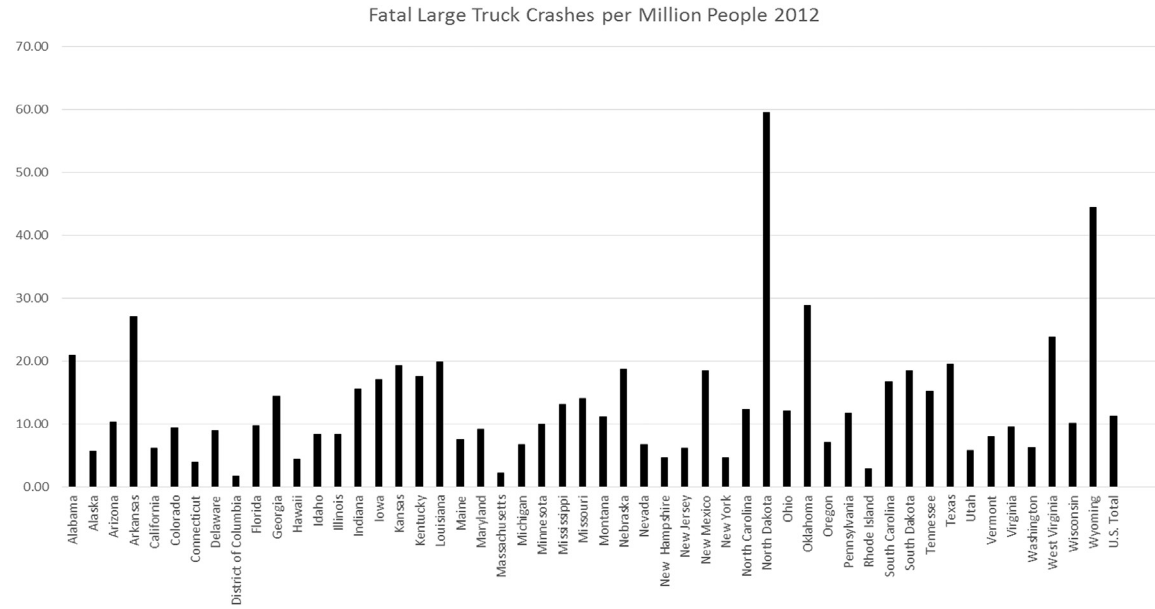

Fig. 1. Truck Crash Rate and Population Density for 2012.

followed by the Wilcoxon Rank Sum test for pairwise comparisons.

Finally, regressions were accomplished for the type of accident involving trucks (fatalities, injury, and property damage) utilizing data from the DoT from 2002 until 2012. These regressions predicted the number of US accidents involving trucks for the type of accident during the time period of July 2013 to June 2014. Three estimates emerged from each of the regressed points: 1) the predicted regressed estimate if no HOS changes occurred, 2) the corresponding projected FMCSA claim estimate, calculated as the estimate if no HOS changes occurred less the anticipated improvement by type of accident (19 fatalities, 560 injuries, and 1400 property damage), and 3) an estimate for the possible reduction of fatigue related accidents computed as deducting 13% from the estimate if no HOS changes occurred. These corresponding points were then analyzed against the Ohio extrapolated point, which is discussed next.

Utilizing the data from Ohio Department of Safety Statistics, accident data was collected from 2002 through 2012 regarding the same types of accidents (fatal, injury, and property damage) and modeled as a function of time (year). This regression provided the estimate of what should have occurred given no change in HOS regulation. This value was divided by the actual number of accidents, by type of accident, providing a corresponding percentage that was used to extrapolate the US estimate for the period from July 2013 to June of 2014. This approach is similar to research used by the National Highway Traffic Safety Administration (NHTSA) to gain awareness of vehicle weights or safety belt use and their relationship with fatalities (Kahane, 1997).

Confidence intervals on the regression lines describing the relationship of type of accident over years were used to examine whether or not the above regression estimates predicted by FMCSA and the Ohio point estimate are within the associated confidence bounds. The magnitude of the FMCSA estimates were compared to the total US accidents, and to the total US accidents that were perhaps caused by fatigue.

Many studies compare the number of accidents to the vehicle miles traveled in order to substantiate a rate that accounts for the quantity of truck miles on the road (Forkenbrock, 1999; Jovanis and Chang, 1986; Miller et al., 1991). This could not be accomplished for this research because it utilized mid-year data (beginning in July and ending in June) where the VMT is reported on an annual basis. Instead, traffic, toll road (a road that drivers must pay directly to use), and gas tax revenue data were examined in order to eliminate or reduce effects from other possible influencing or confounding factors (Downs, 1992). In addition, toll roads break down the vehicle class providing data on the actual vehicles on toll ways, just as gas tax revenue similarly estimates traffic congestion (Newman and Kenworthy, 1989).

All analyses assumed an alpha equal 0.05 level of significance and were conducted primarily using JMPv11.0 software. Results concerning the analyses of the previously mentioned nine variables of interest are presented in the next section.

4. Analysis

4.1. Pre-HOS vs. Post-HOS analysis

Summary statistics for fatalities are shown in Table 2. Although there was a drop in fatal accidents from pre-HOS (mean 10.48 and median 10) to post-HOS (mean 9.17 and median 9.5), this decrease was not statistically significant (p-value=0.309). Incongruously, fatality accidents caused by truck drivers rose slightly from pre-HOS (mean 3 and median 3) to post-HOS (mean 3.42 and median 3). However, this increase was also not significant (p-value=0.586).

Conversely, paired *t*-tests (see Table 3 and Table 4 where significant p-values are shaded) indicate there are significant differences between pre- and post-HOS periods regarding injury and property damage accidents involving trucks. Total injury accidents decreased in the post-HOS by a mean difference of 51.75 per month (p-value < 0.001). Furthermore, the mean number of injuries caused by truck drivers decreased in the post-HOS by greater than 22 accidents per month (p-value =0.007). Additionally, property damage accidents involving

Table 2
Comparison of pre- and post-HOS fatal accidents.

Causation category	Statistical category	PRE HOS (48 Months) July 2009–June 2013	POST HOS (12 Months) July 2013–June 2014	(Pre vs Post HOS) P-Value
Fatal accidents involving trucks	Mean	10.48	9.17	0.309
	Standard deviation	3.57	4.61	
	Median	10	9.5	
Fatal accidents caused by truck driver	Mean	3	3.42	0.586
	Standard deviation	1.79	2.35	
	Median	3	3	

Table 3
Injury accident analysis.

Causation category	Statistical category	PRE HOS (48 Months) July 2009–June 2013	POST HOS (12 Months) July 2013–June 2014	(Pre vs Post HOS) P-Value
Injury accidents involving trucks	Mean	293.25	241.5	< 0.001
	Standard deviation	41.68	62.94	
	Median	298.5	241	
Injury accidents caused by truck driver	Mean	152.48	129.83	0.007
	Standard deviation	24.39	28.37	
	Median	155	126.5	

Table 4
Property damage accident analysis.

Causation category	Statistical category	PRE HOS (48 Months) July 2009–June 2013	POST HOS (12 Months) July 2013–June 2014	(Pre vs Post HOS) P-Value
Property accidents involving trucks	Mean	1178.04	937.83	< 0.001
	Standard deviation	183.66	223.77	
	Median	1174	937	
Property accidents caused by truck driver	Mean	701.29	569	< 0.001
	Standard deviation	108.82	132.83	
	Median	707	533	

trucks decreased in the post-HOS by approximately 240 per month, and by 132 property damage accidents caused by truck drivers (p-values < 0.001).

4.2. 12-Month increments analysis

In order to account more accurately for the general decreasing trend in accidents with respect to time, the 48-month block pre-HOS is now broken down into four periods. Each period consists of 12 month (July to June) ranging from 2009 to 2013.

Fatal accidents caused by truck drivers during the post-HOS were not significantly different from any other year during the pre-HOS, based on a Friedman test (p-value =0.208), nor were fatality accidents (p-value =0.425). The box and whisker plots of these years regarding fatalities can be seen in Fig. 2.

Fatality data was broken down further by providing overall rank and p-value differences based on the Wilcoxon Signed Rank tests. The 12-month comparisons for fatalities were non-significant. Fatalities caused by truck drivers, in the post-HOS period, were the second highest average rank period, but were the lowest in fatalities involving trucks. Although insignificant (p-values from 0.064 to 0.999), the number of fatalities involving trucks post-HOS were lower while the number of fatalities post-HOS caused by truck drivers were higher from the previous years.

Table 5
Injuries involving and caused by trucks contrasted by year.

		Injury accidents			
		Involving a truck		Caused by truck	
Reference year	Contrasted year	Mean difference	P-Value	Mean difference	P-Value
July 2013–June 2014 (Post-HOS)	2012–13	−10.92	0.518	−3.08	0.744
	2011–12	−54.67	0.002	−25.42	0.009
	2010–11	−82.92	< 0.001	−38.42	< 0.001
	2009–10	−58.50	< 0.001	−23.67	0.021
July 2012–June 2013	2011–12	−43.75	0.012	−22.33	< 0.001
	2010–11	−72.00	< 0.001	−35.33	0.033
	2009–10	−47.58	0.006	−20.58	0.002
July 2011–June 2012	2010–11	−28.25	0.098	−13.00	0.172
	2009–10	−3.83	0.820	1.75	0.853
July 2010–June 2011	2009–10	24.42	0.151	14.75	0.122

Table 5 and Table 6 depict mean differences between each 12-month period regarding injuries, and property damage. There were significant differences between means number of accidents of at least some of the 12-month periods (ANOVA p-value < 0.001). Shaded values indicate that the reference year is significantly different from the contrasted year. The LSD pairwise results suggest a greater mean change between larger time spans confirming a downward slope of occurrences over time. Consequently, it is more likely that the post-HOS period is most comparable to the preceding 12-month period. As such, post-HOS data is not significantly different from the previous 12-month period in terms of injury, property damage, or total accidents. As an illustration of this point, injuries caused by truck drivers during the period of July 2013–June 2014, and the previous 12 months indicates a mean difference of −3.08 at a non-significant p-value of 0.744. When comparing the July 2013-June 2014 period with the period beginning in 2011 and ending in 2012, the mean decreased by 25.42 with an associated significant p-value of < 0.009. The two main concepts from these tables are: 1) overall, there has been a downward trend in accidents involving and caused by truck drivers during the period studied and 2) the post-HOS year is not significantly different from the previous year in terms of injuries, and property damage caused or involved with truck drivers. The analysis results suggests that HOS may not have improved safety, by any significant means, more

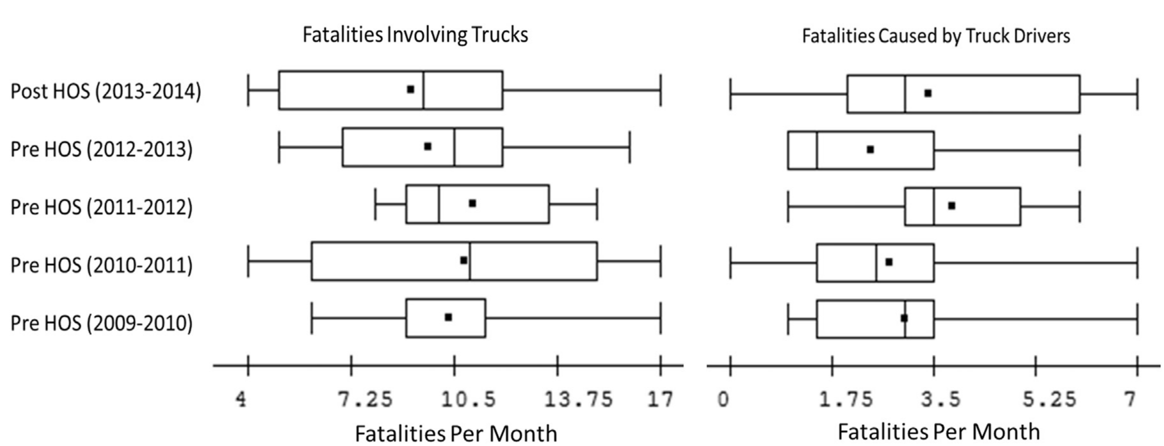

Fig. 2. Box and Whisker fatalities caused and involved with truck drivers in Ohio.

Table 6
Property damage involving and caused by trucks contrasted by year.

Reference year	Contrasted year	Property damage accidents			
		Involving a truck		Caused by truck	
		Mean difference	P-Value	Mean difference	P-Value
July 2013–June 2014 Post-HOS	2012–13	−85.83	0.242	−46.25	0.290
	2011–12	−288.42	< 0.001	−170.08	< 0.001
	2010–11	−321.00	< 0.001	−178.17	< 0.001
	2009–10	−265.58	< 0.001	−134.67	0.003
July 2012–June 2013	2011–12	−202.58	< 0.001	−123.83	0.006
	2010–11	−235.17	< 0.001	−131.92	0.004
	2009–10	−179.75	0.016	−88.42	0.046
July 2011–June 2012	2010–11	−32.58	0.655	−8.08	0.853
	2009–10	22.83	0.754	35.42	0.417
July 2010–June 2011	2009–10	55.42	0.448	43.50	0.320

than what had already been naturally occurring.

4.3. Percent of truck drivers at fault analysis

An analysis of percentages rather than actual values associated with truck-related accidents can yield additional insights. Looking at the percentage of crashes caused by truck drivers out of the total number of crashes involving trucks provides a better comparison between years, which may involve differences in things like highway technologies, road construction, vehicle safety equipment, traffic congestion, weather, etc. Since HOS only targeted truck drivers, it would be intuitive that the percentage of truck drivers at fault would drop due to the added benefit of the safety regulation.

Table 7 presents the percentage of truck drivers at fault for fatalities, injuries, and property damages involving trucks. Across all of these categories, the percentage of accidents caused by truck drivers increased during this period. This indicates that more truck drivers are responsible for accidents occurring; however, these trends were not statistically significant (p-value between 0.113 and 0.247).

Percentage data were further stratified into the five 12-month periods beginning in July and ending in June (see Table 8). The post-HOS period has a higher mean across all measures than all the prior years, however, this difference was only significant for fatalities caused by truck drivers when compared to the previous year 2012–2013 (p-value=0.026). However, many of the contrasted years were non-significant when compared to the post-HOS with p-values ranging from 0.054 to 0.881.

4.4. Ohio extrapolation to the US analysis

Extrapolating the Ohio data to the US is important to gain insight on the impact of HOS across the US and to compare the results to FMSCA's FMCSA's predictions of 19 lives saved, 560 injuries prevented, and 1400 property damage accidents avoided. The regression estimates what the US should have seen during the period from July 2013 to June 2014 if the 1 restart per 168 h and 1 a.m. to 5 a.m. was not implemented. These three estimates (fatality, injury, and property damage accidents involving trucks) are labeled US regression estimate in Table 9.

Table 7
Post and pre HOS percent distributions.

Accident type caused by truck driver	Pre-HOS Mean% (Standard deviation)	Post-HOS Mean% (Standard deviation)	(Pre- vs Post-HOS Mean) P-Value
Fatal	28.28% (13.99% Std Dev)	36.72% (23.67% Std Dev)	0.114
Injury	52.04% (4.45% Std Dev)	54.46% (5.43% Std Dev)	0.113
Property damage	58.63% (3.33% Std Dev)	60.92% (3.75% Std Dev)	0.247

The associated FMCSA predictions are subtracted from these estimates providing an approximate amount of change that the revised HOS regulations should have achieved. The next column, labeled Ohio extrapolated point on US fatalities, indicates the change extrapolated from the Ohio data (fatality, injury, property damage) during the period from July 2013 to June 2014. This value is a prediction, based on Ohio, of the impact of the 1 restart per 168-h restriction and the 1 a.m. to 5 a.m. provision had on truck-safety in the US. The last column, labeled US regression estimate reduced by 13% fatigue accidents, depicts points that are considered what could be achieved if the 13% of fatigue related accidents did not occur. In all cases (fatality, injury, property damage), the Ohio extrapolated point for the US indicates safety was not lower than the US regression point.

Fig. 3 illustrates the property damage accidents involving trucks example discussed in the previous paragraph. This figure highlights the close nature of three of the four estimates: predicted estimate if no HOS change occurred, FMCSA's prediction estimate on the reduction of accidents due to the change of HOS, and the Ohio extrapolated estimate. This is important to note because it shows that the Ohio extrapolated point increased accidents in the US by a marginal amount and not decreased them by the marginal amount predicted. Comparing these three estimates to the possible 13% reduction that are currently attributed to fatigue visually shows that this rule was minimally predicted to reduce fatigue related accidents among truck drivers.

Table 10 further depicts the magnitude of FMCSA's predictions on reducing fatigue-caused accidents among truck drivers. As previously stated, FMCSA predicted HOS would reduce US truck-related fatalities by 19, injuries by 560, and crashes by 1400. When compared to the aggregate number of US truck-related accidents, the FMCSA predictions amounts to approximately 0.5% reduction of deaths, injuries, or property damage involving trucks. Utilizing the 13% of fatigued-caused accidents and the DOT data from 2012 indicates that truck driver fatigue accounted for 510 fatalities, 13,520 injuries, and 32,890 accidents involving property damage. Reducing these numbers by the predicted FMCSA predictions results in 491 fatalities (a 3.7% reduction), 12,960 injuries (a 4.1% reduction) and 31,490 (a 4.3% reduction).

4.5. Eliminating an alternative explanation

To avoid drawing the wrong conclusions about the impact of HOS on driver safety, it is important to demonstrate that changes to the frequency of accidents are not the result of an increase or decrease in vehicles on the road. Although there is no data to show how many vehicles are on all the roads, it is possible to estimate the amount of vehicles driving by comparing the amount of gasoline and diesel gallons taxed and validating the estimate using turnpike traffic. Fig. 4 depicts the number of gallons taxed from July 2009 through June 2014 for the state of Ohio. During this period, gas purchases decreased by a mere 0.35% while diesel purchases increased by 0.64%, and total gallons of fuel purchased increased by only 0.29% over the entire 60-month time period. Similarly, vehicles on the turnpike followed consistent yearly patterns during these 60 months, as depicted in Fig. 5. The majority of vehicles on the road are class 1 (low two-axle) followed by class 5 (high 5-axle). The peaks (summer) and lows (winter) are the changes in traffic flow that occurs throughout the calendar year.

When combined, these two classes of vehicles account for 94.5% of all vehicles. Over the 60-month time period, vehicle traffic on the Ohio Turnpike changed by the following amounts: 0.01% decrease in class 1, 0.05% increase in class 5, and 0.03% increase in all classes. The Ohio

Table 8
Ohio percent of accidents caused by truck drivers least significant difference.

		% Fatality caused by truck		% Injury caused by truck		% Property damage caused by truck	
Reference year	Contrasted year	Mean difference	P-Value	Mean difference	P-Value	Mean difference	P-Value
July 2013-June 2014	2012–13	13.61	0.026	1.87	0.295	0.92	0.476
	2011–12	0.9	0.881	2.2	0.220	0.53	0.681
	2010–11	11.77	0.054	2.46	0.171	1.33	0.305
	2009–10	7.46	0.217	3.15	0.080	2.38	0.069

Table 9
HOS analysis.

	US regression estimate	US regression estimate reduced by FMCSA prediction (19 Lives, 560 Injuries, 1400 Property Damage)	Ohio extrapolated point on US accidents involving trucks	US regression estimate reduced by 13% fatigue accidents
Fatalities involving trucks	3249	3230 (−0.58%)	3263 (+.43%)	2827 (−13%)
Injuries involving trucks	72364	71804 (−0.77%)	75826 (+4.78%)	62956 (−13%)
Property damage involving trucks	197473	196073 (−0.71%)	199873 (+1.21%)	171801 (−13%)

*Data obtained from DoT website for fatalities during years 2002–2012, on June 7, 2014.

Turnpike data reveals that all classes of traffic changed by a rate corresponding with fuel taxes. Both figures have highs and lows that indicate the seasonality of driving, which is captured in the analysis by ensuring the same months (July–June) of the given year remains constant.

Since both figures show that there were only negligible changes to vehicle traffic between the various 12-month periods and the use of fuel in Ohio, overall changes in traffic were ruled out as a potential cause of the changes in truck-related accidents and no adjustments were made to account for them as part of the analysis.

In addition, other factors may have influenced the data regarding the number of accidents that cannot be ruled out. Some of these include road construction, weather and atmospheric conditions, automotive safety features and technologies, and other changing laws. It is also possible that these aspects could have impacted truck drivers more than motorists, which may have altered the percent of trucks at fault.

5. Discussion

Comparing the accidents involving truck drivers prior to the 1 restart per 168-h restriction and the 1 a.m. to 5 a.m. provision to the accidents after the HOS changes indicated a significant difference for both injuries and property damage. This analysis showed that pre-HOS injuries caused by or involving truck drivers (both <0.001) and property damage caused by or involving truck drivers (<0.001 and 0.007 respectively) were significantly lower than post HOS accidents of the same type (See Tables 2, 3 and 4). However, the difference in fatalities caused by (p=0.589) or involving truck drivers (p-value =0.309) were not significant. At first glance, it is possible to think that the HOS change significantly reduced the accidents involving truck drivers. However, the significance does not appear to be the result of the HOS change but rather the steady downward trend of the number of accidents that is continually occurring.

The trend of the number of accidents involving trucks, as annotated in the literature review, has been on a continuous decline. This decline is also revealed in the test results shown in Tables 5 and 6. These tables generally indicated that the reference year is most similar to the most recent contrasted year. For example, in Table 5, the Least Square Difference (LSD) between July 2013-June 2014 and the 2012–2013 year had a mean difference of −10.92 (p-value =0.518 for injuries involving trucks and a −3.080 (p-value=0.744) for injuries caused by trucks. As the contrasted year becomes further away with respect to time, the mean difference tends to grown and the p-values become significant: indicating a downward trend for this type of accident.

In order to more accurately account for this general downward trend, the percentage of accidents caused by truck drivers were also analyzed, and the pre-HOS group was divided into four separate years and reanalyzed. The percent of accidents caused by truck drivers are very different from the number of accidents caused or involving trucks. The percentage of accidents caused by truck drivers should theoretically change when new safety technologies, improvements in training, or beneficial regulations emerge, which only effects truck drivers. Although not significant, this research found that the percent of truck drivers at fault increased in all three categories: fatal from 28.28% to 36.72% (p-value=0.114), injury 52.04% to 54.46% (p-value=0.113), and property damage from 58.63% to 60.92% (p-value=0.247). This percentage increase of truck drivers at fault suggests that the HOS revision was not beneficial to the safety of truck drivers and motorists on roads with truck drivers.

Separating the pre-HOS into four separate years on the number of accidents involving and caused by truck drivers was also important to minimize the downward trend of accidents for statistical testing The tests showed no significance difference between the year the 1 restart per 168-h restriction and the 1 a.m. to 5 a.m. provision was in place to the previous year (see Tables 5 and 6). This suggests that the number of accidents were neither increased nor decreased to a significant level due to the HOS change.

Upon further testing the percent of truck drivers at fault for fatalities, injuries, and property damage accidents by separating the pre-HOS into four years yielded some significant results. First, there was a significant difference (increase) in the percent of truck drivers causing fatalities during the 1 restart per 168 h restriction and 1 a.m. to 5 a.m. provision from the previous year not under this regulation (p-value=0.026 see Table 8). Although this same percent was higher than the other contrasted years, it was not at a significant level except when it was compared to the previous year. The percent of injuries and property damage caused by truck drivers was also at its highest during the 1 restart per 168 h and 1 a.m. to 5 a.m. HOS regulation period, but it too was not at a significant level (with p-values ranging from 0.069 to 0.681 see Table 8).

Extrapolating the HOS impact on accidents involving trucks from Ohio to the US was important to compare the point estimates to FMCSA's predictions regarding truck accidents and to understand the possible overall impact in the US. Fatalities, injuries, and property damage involving trucks were all above the regressed estimate for that time period (see Table 9 and Fig. 3). This suggests that more accidents

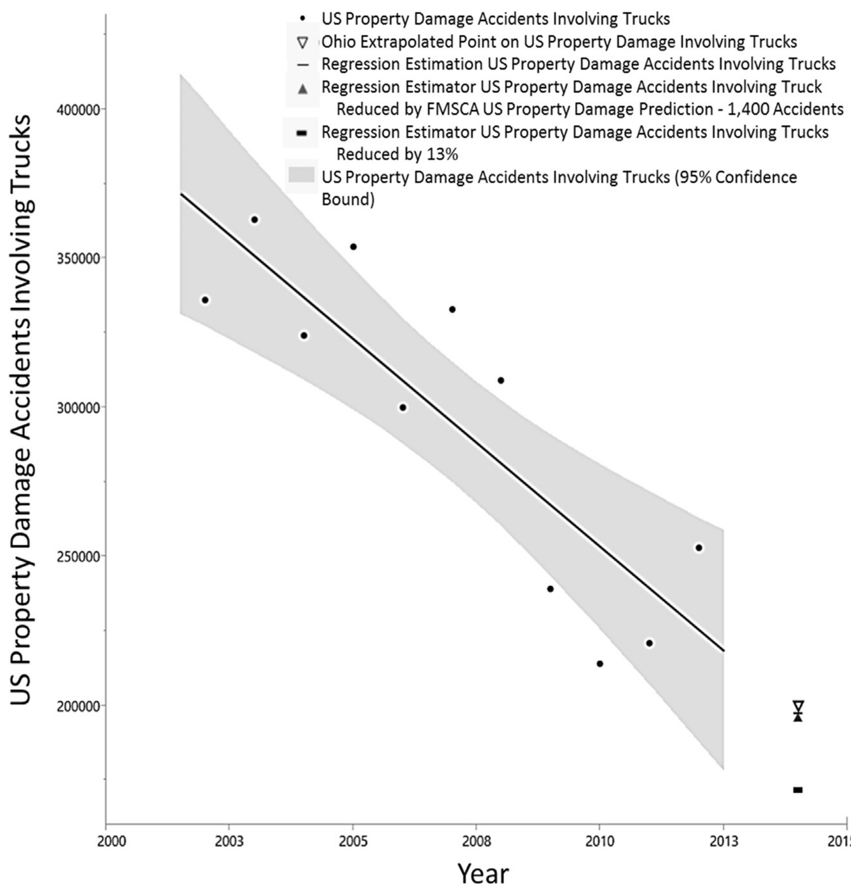

Fig. 3. HOS analysis on property damage accidents involving trucks.

Table 10
FMA'sFMCSA's predicted fatigue based on HOS implementation.

Column	A FMCSA (2013) predicted change due to HOS	B DOT Data (2012)	C % Change	D FMCSA (2007) incidents caused by fatigue (13%)	E Predicted reduced driver fatigue incidents	F HOS change on fatigue
Deaths	19	3921	0.48%	510	12.52%	3.7%
Injuries	560	104000	0.54%	13,520	12.46%	4.1%
Property damage	1400	253000	0.55%	32,890	12.45%	4.3%
*Formula			=A/B	=13%*B	=D-A	=A/D

occurred during this period then what FMCSA projected for all categories.

This research is unable to determine if the HOS change resulted in the reduction of 19 fatalities, 560 injuries, and 1400 property damage accidents involving trucks. It is very possible that this regulation did result in saving lives and preventing fatigued related accidents and there are other factors that resulted in an increase in accidents involving trucks. The amount of traffic on roads was ruled out because traffic remained approximately the same during the studied period (see Figs. 4 and 5). However, the FMCSA predictions are a very small percentage of accidents that occur annually in the US involving trucks. As demonstrated in the analysis, 13% of accidents involving truck drivers have been attributed to fatigue. This 13% translates to 510 fatalities, 13,520 injuries, and 32,890 property damage accidents in the US for 2012 (see Table 10). FMCSA predicted that HOS would reduce by 4% the number of accidents caused by fatigued truck drivers and reduce by approximately 0.5% the number of total accidents involving trucks (see Table 10). Although these reductions are not inconsequential, finding a significant difference from these small predictions becomes more challenging. It is also important to note that the predictions from the HOS regulations do not address the other 96% of accidents allegedly caused by fatigued truck drivers. Given the cost and challenges of implementing HOS, addressing only 4% is problematic and further research is needed to provide greater results in the reduction of truck driver accidents due to fatigue.

6. Conclusions

There are many important managerial findings from this research that utilized Ohio data: 1) Significant differences exist between pre- and post-HOS regarding the number of injuries, and property damage accidents involved and caused by truck drivers but not for fatalities, 2) Recent HOS changes (1 restart per 168-h restriction and 1 a.m. to 5 a.m. provision) did not significantly change the continuing downward trend of accidents involving trucks, 3) When analyzed using 12-month periods, post-HOS number of accidents involving or caused by truck drivers is not significantly different than the prior 12 months in any category, 4) Percent of accidents caused by truck drivers from July 2013 to June 2014 increased for fatalities, injuries and property damage accidents (p-values between 0.113 and 0.247), suggesting that the HOS changes (1 restart per 168 h restriction and the 1 a.m. to 5 a.m. provision) made truck drivers more likely to be at fault for the accident than the period of July 2009 to June 2013, which was prior to the change; also, the percent of fatalities caused by truck drivers was significantly higher (p-value =0.026) than the previous year, which was not regulated by the 1 restart per 168 h restriction and the 1 a.m. to 5 a.m. provision, 5) The regression analysis and point estimates show that the US fatalities for the period of July 2013 to June of 2014 (1

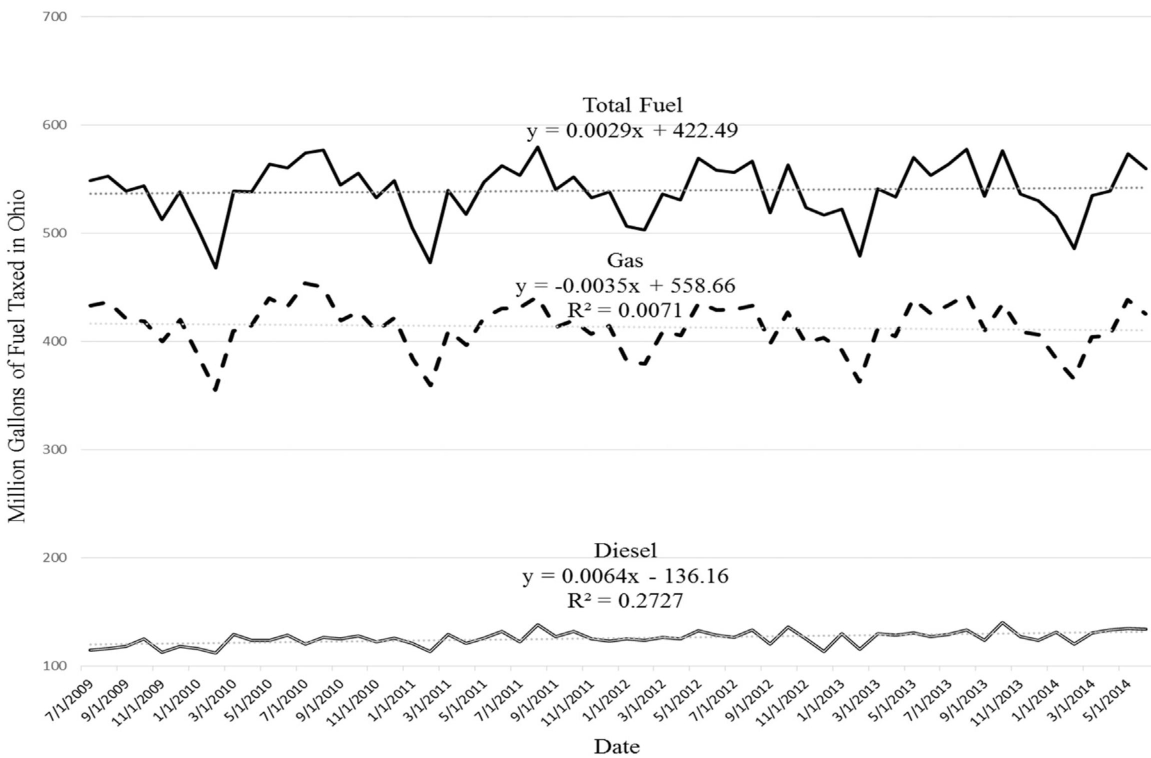

Fig. 4. Ohio million fuel gallons taxed 2009–2014.

restart per 168 h restriction and the 1 a.m. to 5 a.m. provision) are slightly above the trend line of accidents in the US. Additionally, this research brings to light the small predicted impact that FMA FMCSA claims HOS will have on fatigued truck drivers; showing that this regulation change in HOS was predicted to reduce all accidents involving trucks by less than 1%, and fatigue-caused accidents by approximately 4%.

Countering fatigue is a difficult, if not impossible, feat for legislators. A "one-size" fits all approach of HOS will have numerous direct and indirect negative safety effects that are difficult to predict. This research has shown that HOS has not decreased the percentage of accidents caused by truck drivers in the state of Ohio. Furthermore, the rate at which accidents had previously been decreasing did not significantly change because of the restart restrictions introduced into HOS.

Enacting new HOS regulations came at a great expense to the individuals, the industry, and ultimately the consumer. In fact, Short (2013) found that 66.3% of truck drivers surveyed were more fatigued and 27.8% were much more fatigued due to the updated HOS restart restrictions. Not only were truck drivers reporting that they were more

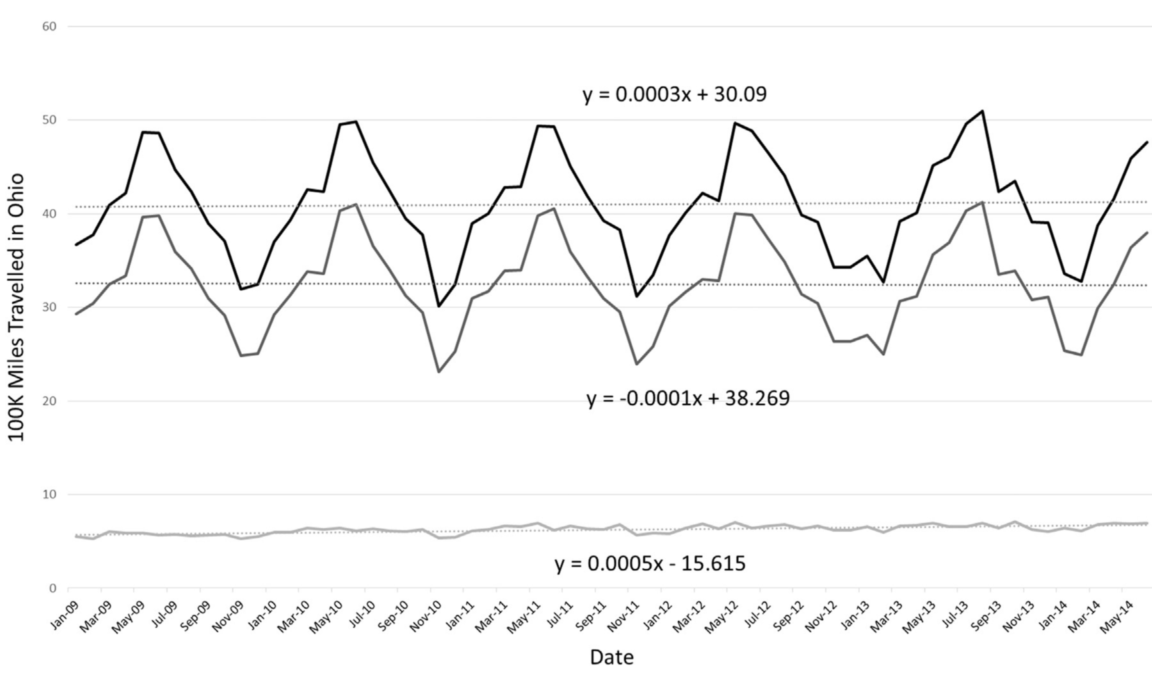

Fig. 5. Vehicles on Ohio Turnpike 2009–2014.

fatigued, but daytime traffic congestion has also increased due to HOS requirements, possibly making roads less safe (Chen et al., 2015; Downs, 1992; Montague, 2014; Short and Murray, 2014).

Better enforcement of other regulations may be a more effective and cheaper alternative to HOS implementation. For example Craft and Blower (2004) demonstrated that 29% of accidents caused by trucks were the result of brake problems on trucks and that fatigue ranked seventh in terms of risk importance. Improved trucking compliance on brake safety could have more than double the impact of attempting to counter fatigue. The bottom line, is when legislation is passed that has questionable effects, more research should be accomplished prior to its implementation.

Accidents are a terrible tragedy. There are many reasons why accidents occur. Government HOS regulations need to be well researched prior to implementation. With respect to the 1 restart per 168 h restriction and 1 a.m. to 5 a.m. provision, thorough research was not completed until 1 year after the enactment of the rule (Ferro, 2014). The eventual suspension of these provisions indicates the very real possibility of some unintended consequences this HOS regulation may have had on truck drivers and motorists. This research has shown that truck drivers within Ohio are *not* causing a smaller percentage of fatalities, injuries, or property damage, the exact opposite of the intent of HOS.

6.1. Future research

The data from Ohio is only a sample. Once data is available at the national level, it too should be explored to better understand the HOS effects on truck driver and overall motorist's safety. Additional analysis should be conducted on other possible causal factors that affect safety that may not be tracked or apparent at this time. For example, high driver turnover may have resulted from the HOS regulation, and high driver turnover has been shown to increase accidents due to a decrease in route familiarity and schedule (Griffin et al., 1992; Staplin and Gish, 2005).

Further studies should examine how other career fields are mitigating fatigue and reducing accidents. For example, the medical field has made numerous improvements to handle fatigue (i.e., ER doctor and staff shifts), while the airline industry has reduced pilot fatigue. The effort of these industries has a lot to offer the trucking industry through benchmarking.

Further research is needed on countering fatigue among truck drivers. Rather than dealing with actual numbers of accidents, research focusing on percentages will yield fewer confounding results by ruling out changes driven by market force innovations that equally affect truck drivers and other motorists. Additional research can also be conducted by expanding the timeframe to the entire period that the 1 restart per 168 h and 1 a.m. to 5 a.m. provision was in place, providing greater numbers and clarity to its impact on truck drivers' safety.

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