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A driver focused truck crash prediction model

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ABSTRACT

This paper advances a driver focused truck crash prediction model. The model investigates the contribution of driver factors on the number of state reportable crashes in which the driver was involved. The findings suggest that the following factors are significantly related to the likelihood of a crash occurrence: driver age, weight, height, gender, and employment stability as well as previous driver and vehicle violations and past crashes. The results have significance regarding the Federal Motor Carrier Safety Administration imperative to improve safety.

1. Introduction

Truck crashes are quite costly to those directly involved as well as to those whose activities are impacted by them. Dwyer (1991) notes that while truck crashes do not attract as much attention in the literature or in the media as does a major industrial disaster, the cumulative consequences are much larger. According to the Federal Motor Carrier Safety Administration (FMCSA), large truck crashes cost around $30 billion annually and result in approximately 5000 deaths and many more injuries (Zaloshnja and Miller, 2007). In addition, truck crashes often block roads for extended periods, causing supply chain disruptions and costly operational delays.

There is evidence that commercial truck safety is an even more important issue than automobile safety. The percentage involvement of commercial trucks in fatal crashes is higher than would be expected given their share of total vehicle miles (trucks and cars). Charlton and Bastin (2000) concluded that in New Zealand, trucks make up only 6% of the total distance traveled in the country but are involved in 22% of all fatal crashes. In addition, the consequences of truck crashes are more serious than car accidents due to weight, size, and maneuvering limitations of the bigger and heavier vehicles. The US Department of Transportation points out that in 2007 there were 4584 trucks involved in fatal crashes. Based on annual truck vehicle miles traveled (VMT), the US DOT indicates that there were 2.02 fatal crashes per 100 million truck miles. In contrast, the US DOT indicates there were a total of 37,248 total fatal crashes in 2007. Based on total annual VMT, there were 1.23 fatal crashes per 100 million miles. The ratio of the fatal truck crash rate to total fatal crash rate in the United States is 1.64 (US Department of Transportation, 2007a,b,c). Given these effects, it is of paramount importance to better understand the factors that can impact crashes, including driver risk factors.

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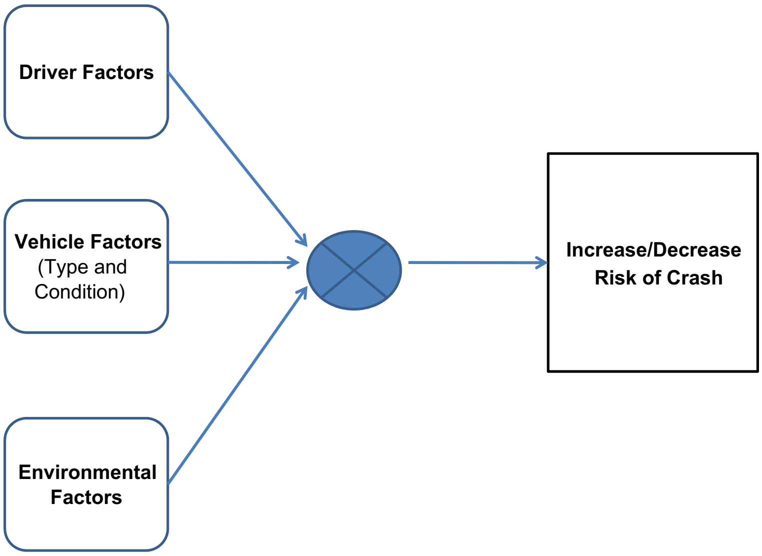

Fig. 1. Classification of major causes of truck crashes.

A substantial amount of literature exists on motor carrier safety. As highlighted in Cantor et al. (2009), there are a wide range of motor carrier management practices available to enhance carrier safety performance including driver recruitment practices (Keller, 2002; Beilock and Capelle, 1990; Dobie et al., 1998; Stephenson and Fox, 1996), driver training (Mejza and Corsi, 1999; Mejza et al., 2003), reducing truck speed (Campbell, 1995), wellness programs (Holmes et al., 1996), and enforcement of hours of service rules (Cantor et al., 2009; Crum and Morrow, 2002; Saltzman and Belzer, 2002). However, research regarding the impact of demographic characteristics of commercial drivers on safety performance is quite limited, as will be discussed in more detail below.

Examining specific driver level factors that contribute to the occurrence of truck crashes is of significant public policy, firm strategy, and scholarly interest. As depicted in Fig. 1, crash incidence is affected by driver factors, vehicle factors, and environment related factors. Driver related factors include fatigue, misjudgment, carelessness, drug and alcohol use, speeding, age, gender, height, weight, and employment stability. Vehicle related factors include vehicle type as well as breakdown and failure of some components, such as tires or brakes. Environmental factors that contribute to crashes involve poor road conditions, adverse weather conditions, and structural and engineering difficulties. According to the Large Truck Crash Causation Report submitted to the United States Congress by the Federal Motor Carrier Safety Administration in March 2006, 87.2% of all truck crashes are caused by driver related factors, 10.1% are due to the vehicle related factors, and 2.3% are related to the environmental factors (FMCSA, 2006). This underscores the importance of developing a driver focused truck crash prediction model. Section 4117 of SAFETEA-LU (Public Law 109-59) directed the FMCSA to address this issue by requiring a central collection and dissemination of commercial driver safety performance and regulatory compliance data across state agencies.[4]

The purpose of this paper is to identify driver level factors that contribute to the increased likelihood of crash occurrence. In doing so, we contribute to the literature on motor carrier safety by creating and testing a model of driver specific factors on safety performance. Our model is tested using a recently created Federal Motor Carrier Safety Administration database of commercial vehicle driver information. This database, labeled as the Driver Information Resource Database, was created in response to SAFETEA-LU Section 4117 of the FMCSA directive. Our goal is to inform scholars, motor carriers, and public policy officials of the most critical driver-based factors impacting the likelihood of truck crashes, thus providing an important contribution to the motor carrier safety literature.

This study represents the first comprehensive use of FMCSA's Driver Information Resource (DIR) database to support the development of a driver focused truck crash prediction model. To the best of our knowledge, we are unaware of any published study that has developed and empirically tested how driver demographic factors contribute to driver safety performance using the FMCSA's DIR database. Previous unpublished studies have been limited in terms of sampling time frame, statistical method employed, and scope of variables considered (Booz Allen Hamilton, 2007; American Transportation Research Institute, 2005).

The next section of this paper develops hypotheses regarding the effects of specific commercial motor vehicle driver factors on safety performance. Following a description of the data and methodology, results of the analysis are presented and discussed.

[4] Federal Motor Carrier Safety Administration website, http://www.fbo.gov/index?s=opportunity&mode=form&id=e24a914d5d4df8ba18dc24548d422a3e&tab=core&_cview=0&cck=1&au=&ck=.

2. Hypotheses

2.1. The effects of driver's involvement in past motor vehicle crashes

The first driver factor of importance in the predictive model is the driver's past involvement in crashes. Findings from prior motor carrier survey research point out that a driver's past safety performance is an important predictor of future safety performance (Mejza et al., 2003). Importantly, in an effort to improve the firm's hiring practices, motor carriers screen applicants based on the driver's historical safety ratings including chargeable crashes. American Transportation Research Institute's (2005, p. 16) study points out that if a truck driver had a crash in the previous year, his/her likelihood of having a crash in the following year is almost twice as high as a driver with no crashes in the previous year. The American Transportation Research Institute's (2005) study also indicates that drivers with past convictions or violations are more likely to have future crashes. Serious violations, such as reckless driving and vehicle crashes were found to increase future crash risk more than minor violations. In fact, Lantz and Blevins (2001) point out that use of the Commercial Driver's License Information System (CDLIS) database is an important way to identify high risk drivers. Lantz and Blevins (2001) analyzed conviction data in the CDLIS database and found that carriers employing drivers with poor safety records will continue to have poor safety scores and higher crash rates. Therefore, we suggest the following hypothesis:

Hypothesis 1. The greater the commercial motor vehicle driver's involvement in past motor vehicle crashes, the greater the likelihood of future crash involvement.

2.2. Driver inspections involving driver and vehicle out-of-service violations and crashes

The condition of a driver's vehicle is an important factor that can contribute to motor carrier crashes. To reduce the likelihood of a truck crash, motor carrier drivers are responsible for inspecting their vehicles prior to initiating a trip in order to detect any mechanical defects. The FMCSA believes that motor carrier driver vehicle inspection is very important and estimated that 10% of all crashes involve vehicle defects as the critical pre-crash causal factor (FMCSA, 2006). The FMCSA's study suggests that the most common vehicle problem involved defective or inoperable brakes. These insights are consistent with Corsi et al. (1984) and Corsi et al. (1988) whom provided initial insight that older trailers and defective vehicles contribute to motor carrier crashes. Similarly, Corsi et al. (1988) found evidence that carriers with rapid increases in maintenance-per-vehicle-mile expenses had more accidents. Therefore, we believe that drivers with a higher percentage of their inspections by safety inspectors in roadside inspections involving vehicle out-of-service violations will have a greater likelihood of future crash involvement. An out-of-service violation is a serious infraction of FMCSA rules and the driver and carrier may not continue to operate the vehicle until the violation is addressed.

In a similar fashion, driver violations detected during safety inspections or through roadside police interventions are an important contributing factor to the likelihood of involvement in future crashes. Some truck drivers take greater risks on the road. Speeding or driving drunk are two examples of this behavior, both of which significantly increase crash risk. Motor carriers are implementing and improving their hiring practices to detect job applicants who have been fined or imprisoned for violating alcohol or drug related laws, speeding or other traffic violations (Mejza et al., 2003). Not surprisingly, Meadows et al. (1998) suggest that there is a strong correlation between traffic violations and his/her crash rate. Sullman et al. (2002, p. 227) utilized a truck driver behavior questionnaire technique and found that "only the violations factor was significantly predictive of having had a crash in the previous 3 years." Therefore, establishing sound hiring practices is important to a carrier's future safety performance. We propose the following two hypotheses dealing with a driver's performance based on inspection records:

Hypothesis 2. The higher the percentage of a driver's inspections involving vehicle out-of-service violations, the greater the likelihood of future crash involvement.

Hypothesis 3. The higher the percentage of a driver's inspections involving driver out-of-service violations, the greater the likelihood of future crash involvement.

2.3. Body mass index and crashes

A commercial truck driver's health, as measured by his/her body mass index, is a crucial factor that contributes to safety performance. Federal regulations require physical fitness and suitability in order to qualify to drive a commercial motor vehicle. Maintenance of health is important as commercial truck drivers are usually subject to many health hazards. Irregular schedules and long hours of work, poor diet and nutrition, exposure to body vibration and exhaust gases, and stress of driving in heavy traffic and bad weather often impact a driver's state of health. Roberts and York (2000) document and provide evidence that commercial truck drivers live an unhealthy life style due to lack of physical exercise. Their findings suggest that less than 10% of all commercial truck drivers do regular aerobic exercises. Consistent with this is the study by Korelitz et al. (1993) reporting that, based on a self-administered questionnaire answered by approximately 2900 male truck drivers: 50% are either overweight or obese; 54% smoked cigarettes; 92% did not exercise regularly; and 23% tested positive on at least one measure of alcoholism.[5] Similarly, Stoohs et al. (1994) found initial evidence that obese drivers presented a twofold higher accident rate than non-obese drivers because of increased daytime sleepiness. As Stoohs et al. (1994) point out sleep disorder breathing (SDB) is more common in obese individuals and a cause of daytime sleepiness. To provide insight into the importance of addressing obesity in the motor carrier industry, Holmes et al. (1996) conducted a study on the effects of nutrition programs on driver health and found that wellness programs can have positive effects on health risk factors. Based on these arguments, we examine driver health using BMI as a proxy. Indeed, the Center for Disease Control (2009) points out that the body mass index (BMI) is an "inexpensive and easy-to-perform method of screening for weight categories that may lead to health problems." We offer the following hypothesis:

Hypothesis 4. The greater the commercial motor vehicle driver's body mass index (BMI), the greater the likelihood of future crash involvement.

2.4. Driver age and crashes

Another important commercial motor vehicle driver demographic characteristic which affects safety is driver age. The importance of examining driver age is magnified by the shortage of qualified truck drivers and the general aging of the workforce, which will also contribute to driver turnover (Suzuki, 2007; Global Insight, 2005; McElroy et al., 1993; Beilock and Capelle, 1990). It is expected that younger drivers will experience more crashes than older drivers. With regard to the former, Sullman et al. (2002) provide evidence that younger truck drivers accumulate more annual miles, drive at higher speeds, and are convicted with more aggressive driving violations than are older drivers. Further, insurance companies determine the rate that they will offer based on a driver's age, among other factors. Young people are usually more risk taking than older people, and this is reflected by male drivers younger than 25 paying higher premiums. Sullman et al. (2002, p. 228) also report that younger truck drivers in New Zealand "experience more crashes than older drivers." Sullman et al. (2002) reason that younger truck drivers may not have sufficient experience to operate heavy and dangerous equipment and, thus, may experience more crashes. Blower (1996) also reports that young commercial drivers are about 50% more likely than middle-aged drivers to be charged with a violation in a crash. Insurance Institute for Highway Safety (2008) has found that drivers between the ages of 18 and 24 have the highest crash rates across all age groups. Based upon these considerations, we offer the following hypothesis:

Hypothesis 5. Drivers under the age of 25 have a greater likelihood of future crash involvement than do older drivers.

2.5. Driver gender and crashes

A truck driver's gender may also affect safety performance. Several studies have found that male drivers have a greater likelihood of involvement in crashes than do female drivers. The Insurance Institute for Highway Safety (2008) reports that male drivers are more often engaged in "risky driving practices including not using seat belts, driving while impaired by alcohol, and speeding." Similarly, Harb et al. (2008) find that male drivers are 1.3 times more likely to be involved in a work zone crash than female drivers. Zhu et al. (2006) find that there is a statistical difference in crash rates of male and female drivers; also, the fatality rate for male drivers was higher than for female drivers. Examining workplace injury rates, Berdah (2008) finds that males have a greater risk of on-the-job injuries compared to females. Given the substantial amount of evidence from the auto safety literature on the relationship of gender and safety, we hypothesize the following:

Hypothesis 6. Male commercial truck drivers will have a greater likelihood of future crash involvement than will female commercial truck drivers.

2.6. Number of individual motor carriers a driver is involved with and crashes

One way that motor carriers place an emphasis on safety as a priority is by retaining drivers for a reasonable period of time. Indeed, the firm's management team expects new hires to maintain employment with the carrier for a reasonable period of time as the recruitment process, orientation, and training costs are very expensive. Employers also look at how long potential employees remained with a former employer to address employment stability concerns. Like any other profession, it takes a commercial truck driver a significant amount of time to learn the business practices of the new employer, including the firm's safety policies and safety culture. Over time, the driver will become acutely aware of the employer's safety expectations governing the use of the firm's equipment, communication practices with dispatchers, and general workplace decision-making behavior, which arguably will result in safer outcomes such as reduced truck crashes. Janssens et al. (1995) concur that longevity and stability with a firm instills into an employee a genuine appreciation of a firm's safety management practices. Thus, we offer the following hypothesis:

Hypothesis 7. The fewer the number of individual motor carriers a driver is involved with, the lower the likelihood of future crash involvement.

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[5] The Korelitz et al. (1993) study is based on a questionnaire of motor carrier drivers. However, it is not clear how alcoholism was measured in the survey instrument.

Table 1
Variables.

Variable	Definition
CRASH	The number of state reportable crashes between September 2007 and June 2008
LAG_CRASH	The number of previous crashes that the driver was involved in the 5 year period ending September 2007
VEHICLE_OOS_RATE	Number of vehicle out-of-service (OOS) inspections/number of total vehicle inspections
DRIVER_OOS_RATE	Number of driver out-of-service (OOS) inspections/number of total driver inspections
BMI	Body Mass Index of truck driver
YOUNGER DRIVERS	Age of the driver: 1 if the driver is 25 years of age or under; 0 if the driver is over 25 years old
GENDER	Gender of truck drivers: 1 for male, 0 for female
NUM_COMPANIES	Number of unique companies that the driver drove for based on the company a driver is associated with at the time of each inspection and crash

3. Methodology

3.1. Sample

Our dataset of commercial motor vehicle drivers is derived from the FMCSA's Driver Information Resource (DIR) database which was created in response to section 4117 of SAFETEA-LU. The DIR database contains the following information for each driver: driver profile from the Commercial Drivers License Information System (CDLIS), including driver age, gender, height, and weight; roadside inspection records for drivers over a 2 year period; and crash records for each driver over a 5 year period. Our dataset is composed of drivers who have a commercial driver's license (CDL) and at least three roadside inspections in a 2 year period ending September 2007. Our dataset consists of 560,695 unique drivers in which there are data on all variables in our analysis.

3.2. Data

Our dataset is derived using two Federal Motor Carrier Safety Administration (FMCSA) administered databases: the Commercial Drivers License Information System (CDLIS) and the Motor Carrier Management Information System (MCMIS). CDLIS is a nationwide database that was mandated by the Commercial Motor Vehicle Safety Act (CMVSA) of 1986 to enforce the policy of "one license and one record for each driver, nationwide." The CDLIS database contains information from a commercial drivers license (CDL). The CDL information is linked to each state's motor vehicle administration (MVA). Each state maintains detailed driver data such as convictions, withdrawals, and other license information such as weight, height, and date of birth. Convictions received in another state are reported to the state of issuance and recorded in the driver's electronic file. Each state's MVA office is federally required to query the CDLIS database before issuing a CDL to make sure that no other MVA has previously issued a license to the applicant.

MCMIS contains safety information of motor carriers and hazardous material shippers, such as roadside inspection reports, crash reports, and motor carrier compliance reviews. Crash and inspection reports at MCMIS include both driver and the employing carrier's information. Each state will first enter the crash and inspection reports into their SAFETYNET database and then report this information to the MCMIS database. The next section discusses the proposed analytical model to investigate the relationship between driver and vehicle characteristics and driver safety performance.

3.3. Measurement of variables

We will first discuss our dependent variable, driver safety performance. Driver safety performance is operationalized by measuring crashes that involve the commercial motor vehicle driver. For each driver in our dataset, we collected data from the CDLIS database on the number of state reportable crashes between September 2007 and June 2008. Thus, all crashes occurred in the 10 month time window subsequent to the time period of the independent variables.

Next, we discuss the independent variables used in our model which are also presented in Table 1.[6] Our first independent variable is the driver's past safety performance (LAG_CRASH), which is defined as the number of previous crashes that the driver was involved in the 5 year period ending September 2007. Our next independent variable is the driver's out-of-service rate (DRIVER_OOS_RATE). We measure DRIVER_OOS_RATE as the number of inspections with driver out-of-service violations divided by the number of total driver inspections during the 2 year period ending September 2007. Our next independent variable is the vehicle out-of-service rate. VEHICLE_OOS_RATE is measured as the number of inspections with vehicle out-of-service violations divided by the number of total vehicle inspections during the 2 year period ending September 2007. As pointed out earlier, an out-of-service violation is a serious infraction of FMCSA rules and the driver and carrier may not continue to operate until the

[6] As demonstrated in Fig. 1, truck crashes depend not only on driver factors but also on vehicle and environmental factors. These theoretical considerations suggest that vehicle and environmental variables should be included in a truck crashes model. However, the DIR database does not contain these variables and thus they are not included in the current study.

Table 2
Descriptive statistics.

	Obs	Mean	Std dev	Min	Max
CRASH	560,695	0.0228	0.153	0	3
LAG_CRASH	560,695	0.190	0.456	0	6
VEHICLE_OOS_RATE	560,695	0.214	0.270	0	1
DRIVER_OOS_RATE	560,695	0.066	0.133	0	1
BMI	560,695	28.546	5.287	10.608	73.829
YOUNGER_DRIVERS	560,695	0.0155	0.124	0	1
GENDER	560,695	0.976	0.154	0	1
NUM_COMPANIES	560,695	1.833	1.030	1	39

violation is addressed. We also measure the number of unique companies (NUM_COMPANIES) that the driver drove for over the 2 year period ending September 2007, based on the company a driver is associated with at the time of each inspection and crash. We measure the age of the driver (YOUNGER_DRIVERS) using a dummy variable. We use the driver's date of birth to measure the age of the driver as of September 2007. The coding of YOUNGER_DRIVERS is a one if the age of the driver is 25 or under, and zero if the age of the driver is over 25. Following the Center for Disease Control and Prevention's definition, we measure the driver's body mass index (BMI) by dividing the driver's weight in pounds by height in inches squared and multiplying by a conversion factor of 703 (CDC 2009). Finally, we measure the gender of the driver (GENDER) using a dummy variable. The coding of GENDER is a one if the gender of the driver is male, and zero if the gender of the driver is female.

A summary of the variables along with descriptive statistics is found in Table 2. As shown in Table 2, we have a total of 560,695 unique records of commercial truck drivers with three or more inspections during the 2 year period prior to September 2007. It is interesting to see that, on average, 97.6% of the drivers are male. The average truck driver has a BMI value of 28.54. 6.6 percent of all driver inspections of an average driver resulted in serious violations (DRIVER_OOS_RATE), while 21.4% of all vehicle inspections of an average driver resulted in serious vehicle violations (VEHICLE_OOS_RATE). The number of carriers an average driver drove for during the 5 year period (NUM_CARRIERS) is at least 1.83.[7] Finally, the independent variables do not show statistically significant correlation above the 0.70 threshold (Cantor et al., 2007; Zhu and Kraemer, 2002), which indicates that these variables are distinct. Given these results, we likely conclude that we can proceed with our model.

3.4. Model specification

Poisson regression models are used to investigate the relationship between the driver level characteristics and driver safety performance. Wooldridge (2003), Gittelman and Kogut (2003), Jensen (1987), Shane (2001), and Shane (2002) specifically note that when the dependent variable is defined in terms of non-negative count data, as is the case here with crashes, Poisson regression is an appropriate methodology. This method has frequently been used in crash studies by a variety of researchers such as Cantor et al. (2009), Keeler (1994), and Rose (1990). As is the case with our data, Shane (2001, p. 1179) points out that "ordinary least squares regression is inappropriate for count dependent variables that have large numbers of zero observations and remaining observations taking the form of small positive numbers." The functional form of our model is presented below:

$$\begin{aligned}\text{CRASH} = \exp[&\beta_0 + \beta_1\text{LAG\_CRASH} + \beta_2\text{VEHICLE\_OOS RATE} + \beta_3\text{DRIVER\_OOS\_RATE}\\ &+\beta_4\text{BMI} + \beta_5\text{YOUNGER\_DRIVERS} + \beta_6\text{GENDER} + \beta_7\text{NUM\_COMPANIES}]\end{aligned}$$

4. Results

We first checked for over-dispersion of the Poisson regression model. An assumption of the Poisson model is that the variance of the dependent variable equals its mean. Accordingly it is appropriate to examine whether this assumption is violated; if so, the Poisson model is over-dispersed (Hausman et al., 1984). We found that our Poisson model is not over-dispersed. Our over-dispersion statistic (alpha), as shown in Table 3, is not greater than the acceptable threshold of 1.0.

Table 3 presents the results from our Poisson regression models. As described in Table 3, Hypothesis 1 (the greater the commercial motor vehicle driver's involvement in past motor vehicle crashes, the greater the likelihood of future crash involvement) is strongly supported at the 0.01 level.[8] Hypothesis 2 (the higher the commercial motor vehicle driver's percent-

[7] Our NUM_COMPANIES variable is potentially underestimated since this variable is based on the company a driver is associated with at the time of each inspection and crash.

[8] We re-estimated our model without the LAG_CRASH variable since we cannot identify individuals who have driven fewer than the full five years of the sample period. The results do not change.

Table 3
Poisson regression results.

Independent Variables	Model 1: poisson regression (dependent variable: CRASH)
LAG_CRASH	0.20*** [0.02]
VEHICLE_OOS_RATE	0.03 [0.03]
DRIVER_OOS_RATE	0.34*** [0.06]
BMI	0.01*** [0.001]
YOUNGER_DRIVERS	0.25*** [0.06]
GENDER	0.21*** [0.06]
NUM_COMPANIES	0.10*** [0.01]
Constant	−4.49*** [0.08]
Obs	560695
Alpha (over-dispersion parameter)	0.981

Log likelihood = −61268.309.
Standard errors in brackets.
** Significant at 5%.
*** Significant at 1%.

age of vehicle out-of-service violations, the greater the likelihood of future crash involvement) is not supported.[9] Hypothesis 3 (the higher the commercial motor vehicle driver's percentage of driver out-of-service violations, the greater the likelihood of future crash involvement) is strongly supported at the 0.01 level. Hypothesis 4 (the greater the commercial motor vehicle driver's body mass index (BMI), the greater the likelihood of future crash involvement) is supported at the 0.01 level. Hypothesis 5 (drivers under the age of 25 have a greater likelihood of future crash involvement than older drivers) is supported at the 0.01 level. Hypothesis 6 (male drivers have a greater likelihood of future crash involvement than female drivers) is supported at the 0.01 level. Hypothesis 7 (the fewer the number of individual motor carriers that a driver is involved with, the lower the likelihood of future crash involvement) is supported at the 0.01 level. We will discuss the implications of each of these finding in the discussion section.

5. Discussion

Our research has developed and tested a model of driver level characteristics and driver safety performance in the context of the US motor carrier industry. In our paper, we have provided statistical evidence that a number of driver characteristics contribute to the crash rate of truck drivers. As highlighted in the introduction, our results support the goal of the Federal Motor Carrier Safety Administration to develop and demonstrate a linkage between driver level safety characteristics and driver safety performance using the recently created Driver Information Resource database (Public Law, 109-59). Therefore, in addition to demonstrating statistical significance, our model also has real world importance.

Our results demonstrate that a driver's past safety performance is a strong predictor of future safety performance. As mentioned previously, truck drivers are regularly faced with situations in which they need to make critical safety decisions by observing conditions on the road. A driver's previous safety record, whether indicative of cognitive limitations, driving behavior, or other factors, is reflective on how the driver will perform in the future.

We found evidence that a driver's out-of-service violation rate is also a strong predictor of safety performance, which is consistent with the FMCSA's Large Truck Crash Causation Report (FMCSA, 2006). As reflected in our driver's out-of-service variable, some commercial motor vehicle drivers take risks while operating their vehicle. We provided some examples earlier of the types of risks that drivers are known for taking including speeding, driving while fatigued, or driving drunk. Public policy efforts are needed to improve the way that we identify those drivers who experience these types of violations.

We also found evidence that the greater the driver's body mass index (BMI), the lower the driver's safety performance. While our measure of BMI is based on self-reported data, it nonetheless serves as an important proxy for the state of a driver's health (Center for Disease Control, 2009). Increasingly, many transportation firms are looking to improve an employee's health so as to address supply chain safety issues (Cantor, 2008; Transport Topics, 2007). One way to do so is through drug and alcohol abuse programs. Beyond these programs, transportation firms are promoting "wellness" programs to improve

[9] We re-estimated our model without VEHICLE_OOS_RATE. The results do not change.

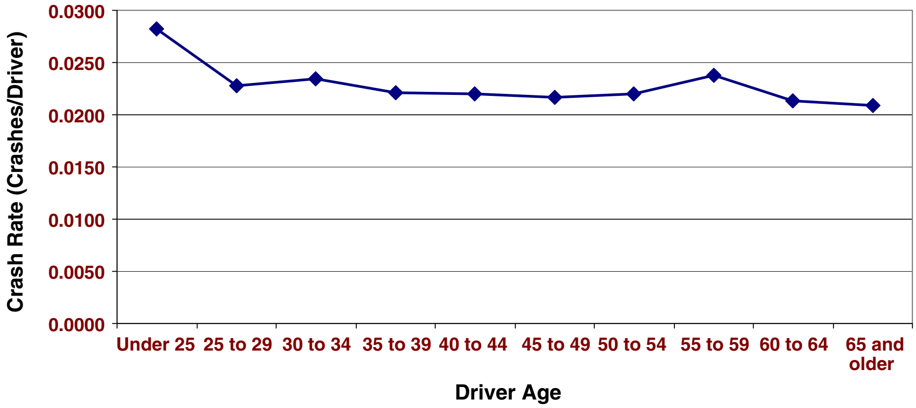

Fig. 2. Crash rate by driver age.

Table 4
Crash rates.

Age group	Crashes	Drivers	Crash rate
Under 25	246	8,703	0.0283
25–29	859	37,665	0.0228
30–34	1386	59,037	0.0235
35–39	1740	78,579	0.0221
40–44	1979	89,948	0.0220
45–49	1958	90,411	0.0217
50–54	1743	79,315	0.0220
55–59	1358	57,192	0.0237
60–64	785	36,779	0.0213
65 and older	482	23,066	0.0209

safety performance (Holmes et al., 1996). Transport Topics reports that Con-way Freight has seen its annual workers' compensation claims drop by 80% since it started a wellness program in 2005 (Transport Topics, 2007). Our results demonstrate that driver health does contribute to safety performance.

Examining the age of drivers in the US motor carrier industry is particularly important. To further explore these results, we now present the crash rate of the drivers across several age intervals in Fig. 2 and Table 4 based on the data in our sample. Fig. 2 and Table 4 show that drivers under the age of 25 have a greater likelihood of future crash involvement than older drivers. Drivers under the age of 25 may not yet have the necessary maturity or skills to drive at safer levels.[10] Our results suggest that the FMCSA should examine the nature of the motor carrier workforce and design appropriate intervention strategies which include a greater degree of driver training.

Our results also suggest that the fewer the companies that the driver drives for, the lower the likelihood of future crash involvement. Intervention strategies could encourage employees to remain with a carrier for longer periods of time as a way to improve safety performance. Undoubtedly, in this industry it is important to promote employment stability in order to facilitate better safety outcomes.

Our results are consistent with previous unpublished research which shows that the demographic characteristics of commercial drivers contribute to safety performance, including age, BMI, and LAG Crash contribute to safety performance (Booz Allen Hamilton, 2007; American Transportation Research Institute, 2005). Our study builds upon and extends these past studies in several ways. First, we utilize a significantly larger sample size and sampling time period of commercial motor vehicle drivers. Second, we utilize a vastly improved statistical modeling approach that examines the relationship of demographic characteristics on safety performance. Third, we develop a more comprehensive set of variables in our model which includes gender of the driver, number of unique companies that the driver drove for, and driver and vehicle out-of-service rates.

While we found support for several of our hypotheses, we did discover a surprising result. We found no support for our hypothesis that the higher the driver's inspections involving vehicle out-of-service rates, the greater the likelihood of future crash involvement. We do point out that while the estimated coefficient for VEHICLE_OOS_RATE is not statistically significant this variable has a positive sign, which is consistent with expectations. Thus, there is some – albeit statistically

[10] A limitation of our data set is that the DIR database does not contain the total number of miles driven for each driver. However, we can not rule out the possibility that younger drivers drive more miles than older drivers.

Table 5
Poisson regression results.

Independent Variables	Model 2: poisson regression (dependent variable: CRASH)
LAG_CRASH	0.19*** [0.02]
MAINTENANCE_OOS_RATE	0.08** [0.04]
LOADING_OOS_RATE	−0.15** [0.07]
DRIVER_OOS_RATE	0.34*** [0.06]
BMI	0.01*** [0.001]
YOUNGER_DRIVERS	0.25*** [0.06]
GENDER	0.21*** [0.06]
NUM_COMPANIES	0.10*** [0.01]
Constant	−4.49*** [0.08]
Obs	560,695
Alpha (over-dispersion parameter)	0.980

Log likelihood = −61263.859.
Standard errors in brackets.
** Significant at 5%.
*** Significant at 1%.

insignificant – support for the hypothesis. To further explore this issue, we disaggregated the vehicle out-of-service violation data into its two major components: vehicle maintenance violations (MAINTENANCE_OOS_RATE) and improper loading/cargo securement violations (LOADING_OOS_RATE) and re-ran the model. Turning to Table 5, we find that the vehicle maintenance violation rate is statistically significant in explaining driver crashes at the 0.05 level. This result is consistent with our expectations that poorly maintained vehicles contribute to poor safety performance. Indeed, poorly maintained vehicles as opposed to improper loading/cargo securement provide the critical link to increased crash probability. Regarding the negative coefficient on the LOADING_OOS_RATE, it is quite possible that commercial drivers operate their vehicles more cautiously when carrying cargo requiring special securement resulting in fewer crashes.

While this study represents the first comprehensive use of the DIR database, there are limitations in our model. More specifically, the DIR database does not include information about the characteristics of the vehicle, type of freight carried, and miles traveled by the vehicle. It also does not include information about environmental factors at the time of each crash. This data set does not contain other driver factors including the total number of miles driven for each driver, driver income, and driver experience.[11] Future research should investigate how these additional factors contribute to crashes.[12]

6. Conclusion

We have investigated the relationship between commercial truck driver characteristics and driver safety performance. The findings suggest that the following driver specific factors are significantly related to the likelihood of a crash occurrence: driver age, weight, height, gender, and employment stability as well as previous driver out-of-service violations rates and past crashes. We also found that poorly maintained vehicles contribute to poor safety performance.

The contributions of the paper to the literature are the creation and testing of a driver model of safety performance. Our model is tested using a recently created Federal Motor Carrier Safety Administration database of commercial vehicle driver information. This paper also contributes to the literature by demonstrating how the results of our model are consistent with previous unpublished research which shows that the demographic characteristics of commercial drivers contribute to safety performance, including age, BMI, and past crashes on safety performance (Booz Allen Hamilton, 2007; American Transportation Research Institute, 2005). Our findings complement and contribute to the safety management literature. We hope that our driver factors study will encourage further research on the current topic of motor carrier and commercial driver safety.

[11] It should be noted that omitted variables, particularly if strongly correlated with hypothesized variables, could bias the results.
[12] For example, future work could include dummy variables reflecting the state in which the vehicle is registered or operated.

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