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Michael H. Belzer
Wayne State University

# Work-Stress Factors Associated with Truck Crashes: An Exploratory Analysis

**Working Paper**

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Michael H Belzer
Wayne State University, USA

Corresponding author: Michael H Belzer, Department of Economics, 2127 Faculty Administration Building, Wayne State University, 656 W. Kirby, Detroit, Michigan 48202, United States. Email: Michael.H.Belzer@Wayne.edu

## Abstract

Researchers have studied truck crashes extensively using methods appropriate for behavior, technology, and regulatory enforcement. Few safety studies associate crashes with economic pressure, a pervasive latent influence. This study uses data from the US Large Truck Crash Causation Study to predict truck crashes based on work pressure factors that have their origins in market pressures on motor carriers and truck drivers. Logistic regression shows that factors associated with the work process, including an index of work-pressure attributes, predict the likelihood that crash analysts consider the truck driver to be the person whose last action could have prevented the crash. While not proving causation, the data suggest that economic factors affecting drivers contribute significantly to truck crashes.

**JEL codes:** J28, J33, L91
**Keywords:**
Commercial motor vehicles, compensation, crashes, economic pressure, heavy goods vehicles, safety, stress, truck drivers, trucking

## Introduction

In 2015, 4,311 large trucks and buses were involved in fatal crashes in the United States (0.124 per million vehicle miles travelled, or VMT), continuing a seven-year upward trend in gross fatal crash numbers, beginning with an all-time low of 3,193 (0.108 per million VMT) in 2009—the low point in the Great Recession and the nadir of U.S. commercial truck and bus traffic. This recent trend reversed the broad downward trend that had prevailed since 1975, when the Department of Transportation began to collect the data (FMCSA [Federal Motor Carrier Safety Administration], 2015). This trend may signal a re-emerging problem. While job characteristics vary, making comparison difficult, the truck driver's occupation is one of the most dangerous in the U.S., even controlling for exposure. The 2003–2008 Census of Fatal Occupational Injuries shows that 5,568 Driver/Sales Workers and Truck Drivers died violently on the job — 17% of all US occupational fatalities (Chen et al., 2014). It also is an unhealthy occupation, creating a significant public policy concern (Chen et al., 2015; Robinson and Burnett, 2005).

Very little research has addressed the upstream causes of commercial motor vehicle (CMV) crashes; research tends to rely on proximal triggers, which are easier to measure and trace. This study, using a multi-relational data set documenting large truck crashes with the intent to identify their causes, provides a unique opportunity to measure the pressures leading to truck crashes. Specifically, does work-related pressure create preconditions for crashes? Trucks and buses operate within high-pressure markets because transportation is a commodity; customers assume that regulations have assured their safety and the safety of the goods they ship so they choose transport based on price and service. The public, too, assumes that modern institutions and technology have removed much of the uncertainty in transport safety. This research will test the hypothesis that work-related pressure on commercial truck and bus drivers leads to highway crashes.

## Literature

Since large trucks engage in commercial activities, a study of commercial motor vehicle crashes should analyze economic forces in the commercial delivery of freight. Previous research has demonstrated a strong relationship between truck driver pay and safety. A survival analysis of individual drivers at a single firm showed that at the mean, every 10% in driver pay rate is associated with a 34% lower probably of crash, and every 10% in driver pay raise is associated with an additional 6% lower crash probability (Rodriguez, 2006)

Belzer and Sedo (2018) used a standard labor supply model along with an extension of that theory to model the particular choice long-haul truck drivers make between lower overall earnings in short-haul compared with higher earnings in long-haul, which requires especially long hours. They constructed a backward-bending labor supply curve, using data from a survey of truck drivers conducted by the University of Michigan Trucking Industry Program (Belman et al., 2005), to demonstrate that they work long hours to achieve target earnings. This analysis showed that at the margin, truck drivers will work more hours if a higher pay rate is offered for the work, up to the current average mileage pay rate in the labor market.[i] As the drivers' pay rate rises to and exceeds the mean, however, they will work fewer hours, trading more leisure for labor as anticipated in conventional economic theory. At the time the data were collected, in 1997 and 1998, road drivers worked on average approximately 64.5 hours per seven-day week (almost 10% more than the legal limit), but as driver pay increased above the mean, drivers reduced their working time to the legal limit and below (Belzer and Sedo, 2018).

A 2010 survey by the National Institute for Occupational Safety and Health (NIOSH) has shown that over-the-road truck drivers continue to work similar unusually long hours, with long-haul truck drivers working an average of 60 hours per week and regularly exceed maximum working hours prescribed by Federal Motor Carrier Safety Administration (FMCSA) hours-of-service regulations (Chen et al., 2015). While economists know that workers make tradeoffs between working and non-working time, this direct relationship between truck driver pay — for both driving and non-driving time — and the economics of working time seems to have received less emphasis in motor carrier safety research than one might expect, especially given the unusually long hours of work.

This and other research suggests that there may be a significant difference in crash rates when drivers are paid by the hour compared with when they are paid piecework. For many years, safety advocates have argued that truck drivers should be paid by the hour to align their incentives with public safety. Some have also suggested that the problem is less due to mileage pay than to the piecework pay structure for non-driving labor; the 2010 NIOSH survey showed that 56% of all employee drivers are not paid for any non-driving labor. Viscelli (2016) found that minimal payment for non-driving labor time led drivers to work between 80 and 100 hours weekly, much of it off the record.

Substantial research has shown both theoretically and empirically that truck driver compensation should predict safety. Efficiency wage theory, along with empirical research testing it, supports the hypothesis that carriers will reap superior performance and greater workforce stability if they pay drivers better total compensation than commercial motor vehicle (CMV) drivers would otherwise expect if they worked for a carrier in a lower-rate segment of the trucking market, and better total compensation than they would otherwise receive in a comparable non-trucking labor market (Yellen, 1984; Bulow and Summers, 1986; Holzer, 1990; Lazear, 1995; Summers, 1988; Weiss, 1990). Reciprocity, or 'fair wage theory', further suggests that drivers who earn better compensation will reciprocate because they believe their employer (or freight broker or motor carrier to which they are contracted) is treating them fairly, and this reciprocity may include both greater productivity and greater safety (Burks, 1999; Fehr and Tyran, 1996; Fehr and Gächter, 1998; Fehr and Schmidt, 2000; Milgrom and Roberts, 2002). Drivers who anticipate deferred compensation in the form of pension or other retirement benefits also will protect those benefits by driving in a responsible manner (Lazear, 1990). However, drivers also are motivated by 'target earnings'; that is, they work until they reach an earnings level sufficient to pay their bills, and when they reach target earnings they will tend to trade leisure for labor and work fewer hours (Belzer and Sedo, 2018).

Researchers have paid insufficient attention to the influence of market pressures on occupational health and safety in trucking (notable exceptions include Mayhew and Quinlan, 1997; Mayhew and Quinlan, 2000; Mayhew and Quinlan, 2006; Quinlan, 2001; Quinlan et al., 2006; National Transport Commission, 2008; Williamson et al., 1996). Much of the research on trucking safety seems to focus on the effectiveness of various engineering interventions, such as information technology, mechanical design, and materials technology, on trucking safety. Additional research focuses on behavioral interventions; among those are regulations designed to limit the effects of drivers' economic preference to work more hours in order to earn more money, such as hours-of-service regulatory limitations. While such efforts are important, they do not address the organizational and market problems directly. As long as economic competition in trucking provides incentives for drivers, motor carriers, and cargo owners in the supply chain to seek economic advantage by undercutting these standards, pressure will remain strong and truckers will comply with standards only insofar as regulators and enforcers can maintain enforcement pressure. In other words, markets and regulations will continue to have opposite internal logics that remain in tension with each other and do not necessarily result in safe operations or achieve safety efficiently.

## Data

This study uses the Congressionally mandated Large Truck Crash Causation Study (LTCCS), a one-time data-collection effort managed by FMCSA in partnership with the National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation (DOT) and their internal contractor, the National Automotive Sampling System (NASS), and their subcontractor, Veridian, using state crash investigators (FMCSA, 2006c, 2006d) The full LTCCS database includes 49 data sets, 34 of which have been concatenated for this analysis. FMCSA's contractors collected data on approximately 1,000 variables (see Appendices A and B) in 967 crashes, including 1,127 large trucks, 959 non-truck vehicles, 251 fatalities, and 1,408 injuries (ibid.). Variable names reflect the relation or dataset from which they were obtained and are the original LTCCS names. The database includes all crashes of trucks larger than 10,000 pounds (4,536 kg), including both local and long-distance trucks; this includes all trucks larger than personal vehicles.

The LTCCS database lacks measures of exposure or case controls. Data collectors elected to proceed into the field without the input of the Committee for Review of the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study. Committee experts insisted that scientific validity would be compromised by the lack of exposure data (in this case, VMT), making it difficult to calculate even an odds ratio (Council, 2003; Hedlund, 2003) To remedy this problem, the Committee engaged James Hedlund and Daniel Blower to develop a method with which researchers could simulate exposure.

Hedlund and Blower (2006) argue that because FMCSA collected no exposure data, the only way to conduct statistical analysis of the LTCCS is by using 'induced exposure'. This method requires analysts to separate out cases in which the truck is assigned the 'critical reason for the critical event' from cases in which another vehicle is assigned the critical reason. If indications of the 'critical event' (in particular, the 'critical reason for the critical event') without which the crash would not have occurred were not attributed to the CMV or the CMV driver, then the exposure was considered to be induced by the actions of others. This does not mean that the CMV or the CMV driver was 'at fault' but more narrowly whether the vehicle or driver is associated with being the prime-mover of the event (Hedlund and Blower, 2006).This method is far from perfect, but at least it allows researchers to separate the crashes in which contractors considered the truck driver to have been the last vehicle operator capable of avoiding the crash from those in which the contractor believed another person or vehicle operator made the final action that made the crash inevitable (Hedlund and Blower, 2006; Blower and Campbell, 2005). This study uses this induced exposure approach and attempts to determine statistical relationships between economic factors and the critical reason for the critical event.

Although local drivers frequently are paid by the hour (some have 'percentage of revenue' and flat 'by the load' pay regimes), almost all long-distance truck drivers earn 'piecework' pay (Belzer, 2000). That is, they are paid by the theoretical distance travelled (a fixed shortest practical distance as calculated by a computer program) or a percentage of revenue (which itself is based on distance, type and value of freight, and other contingencies such as weight, volume, and handling characteristics that contribute to the market-driven freight rate), or by the load (which is the same as the foregoing, only more opaque). Some drivers are paid by the hour for some or all non-driving labor time (such as loading, unloading, or waiting for freight or repairs) or at least paid a flat rate per stop or per activity; many long-haul drivers, however, are not paid at all for non-driving labor time. Piecework payment therefore tends to put productivity pressure on the driver. Specifically, Thompson et al. show the inherent logic of work pressure using a simulation of an agent-based model in which economic pressures create incentives for risky behavior (Artz and Heywood, 2015; Braver et al., 1992; Prendergast, 1999; Thompson et al., 2015).

This analysis narrows the definition used by LTTCS to drivers of large commercial trucks only. For this study, analysis is further limited to those drivers holding a Commercial Driver License (CDL) and operating trucks requiring a CDL (weighing more than 24,000 pounds [10,866 kg]).

### *Dependent Variable*

The LTCCS 'uses a method developed by [Kenneth] Perchonok, a late associate of the Veridian staff, that identifies for each crash a critical event and critical reasons for that event' (Perchonok, 1972; Treat et al., 1977; Council, 2003: 59). In almost exactly 50% of all crashes, the truck or truck driver was assigned the 'critical reason for the critical event' (ACRCriticalEvent) and the codebook specifies 64 different reasons ranging from falling asleep to having a heart attack to unknown. This does not mean that 50% of all large truck crashes are caused by truck drivers; this is an unexplained circumstance of the study and perhaps a consequence of hindsight bias (Donaldson, 2005). It means, however, that this variable, used as a dependent variable in the logistic regression, is evenly distributed in attribution between truck and non-truck drivers.

### *Independent Variables*

The variable GVE CDL Truck indicates those vehicles that fall as close to the definition of CMV as is possible within the LTCCS data set. The data set defines the category as greater than 12,000 kg (26,455 pounds), which is the approximate threshold that requires a driver to hold a CDL. For ACRCriticalEvent, controls for GVE Truck and GVE CDL Truck did not change the outcome materially; the difference between them is only the size of the truck. In fact, there is little difference in most variables when controlling for these two categories. When analyzed using logistic regression, different truck designations are not statistically significant in any model.

Data collectors did not collect data symmetrically on automobiles and their drivers as well as on trucks and truck drivers. In other words, because the FMCSA carried out the LTCCS to understand the causes of large truck crashes only, investigators did not believe they could compel cooperation by automobile drivers, leaving data on crashes involving both cars and trucks incomplete. In addition, 107 cases had to be thrown out because they came from the pilot phase of the LTCCS.[ii]

'Fatigue', another variable in the LTCCS, was attributed stably as a factor in about 15% of all crashes and almost only on the part of the truck driver, for the reason discussed above. While fatigue is extremely important (Panel on Research Methodologies and Statistical Approaches to Understanding Driver Fatigue Factors in Motor Carrier Safety and Driver Health, 2016), data collectors did not systematically collect fatigue data from automobile drivers so there is no real way to compare the groups; analysis can reveal only the extent to which data collectors judged fatigue to be a factor for the truck driver. Finally, the complex derived concept 'Fatigue' only crudely approximates the true state of alertness of the driver, so readers should interpret any analysis using this variable with caution. Researchers often call this kind of variable a 'dummy' because it is a 'dumb' placeholder for a concept, and when the concept actually is complex, using such an indicator variable (1/0) may be misleading. However, this Fatigue variable is included in the analysis on the assumption that it will account for some of the variation in the regression analysis and while imperfect, it is the best proxy for fatigue available in these data.

AggressionCount (an ordinal variable) is computed from the following variables in the DriverDecisionAggression data set of the LTCCS: SpeedingBehavior, TailgatingBehavior, Weaving, LightViolation, RapidAcceleration, Honking, Flashing, ObsceneGestures, BlockingOthers, and OtherAggression. It is a construct created by the LTCCS data development team. Prior research suggests that these attributes may contribute to crashes. AggressionCount is included in this analysis because it is reasonable to believe that aggressiveness is related to work-pressure, at least in part.

WorkPressureCount, a variable that exists in the LTCCS data, provides an incomplete measure of the pressure factor, a 'count of the number of work pressure variables'. WorkPressureCount includes the attributes NewPosition, ShippingDeadline, EXPWorkPressure, Quotas, ExtraLoads, Demoted, SelfInducedIllegal and SelfInducedOther (both variables have the same definition), and OtherPressure. An examination of the variable reveals that at most only two attributes are coded to each case, making interpretation very difficult; only fourteen cases had two attributes and data collectors coded only 118 cases for any work pressure attributes.

To expand the analysis using this concept, I developed a summative index based on factors known in the industrial relations field to create work pressure, which expands the number of attributes in the concept. WorkPressureTotal incorporates NewPosition, ShippingDeadline, EXPWorkSchedule, Quotas, ExtraLoads, Demoted, SelfInducedIllegal, SelfInducedOther, OtherPressure (the variables in the original work pressure variable), as well as LoadPressureIndicator, ShortNoticeTrips, FillInTrips, UnpaidLoading, OtherRelations, and Hurrying. The use of a derived variable constructed from a much larger set of variables for the WorkPressureTotal index allows us to treat it as an ordinal continuous variable, since drivers have from zero to seven of these attributes and the index only counts the presence or lack of presence of a code for each.[iii]

**Table 1: WorkPressureTotal**

| | |
|---|---|
| NewPosition | 18 |
| ShippingDeadline* | 1 if the driver experienced work pressure as a result of being under time-related pressures associated with production/shipping deadlines |
| EXPWorkSchedule* | 1 if the driver was experiencing any pressure on the job as it relates to his/her work schedule |
| Quotas* | 1 if the driver experienced any work pressure with regard to additional production or sales requirements |
| ExtraLoads* | 1 if the driver was under pressure from his/her employer to accept loads with little or no advance notice |
| Demoted* | 1 if the driver had recently been forced to accept a demotion and/or pay decrease |
| SelfInducedIllegal and SelfInducedOther* | 1 if the driver experienced self-induced work pressure, as opposed to employer-induced pressure"; both variables have same definition |
| OtherPressure* | 1 if the driver experienced any work-related pressure that was not captured under other work-pressure variables |
| LoadPressureIndicator | 1 if the driver was under pressure to accept scheduled and unscheduled loads, loads proffered on short notice or when over legal driving hours |
| RotatingShift | 1 if the driver experienced work pressure due to his/her carrier scheduling trips in a manner that requires the driver to work rotating shift schedules with an associated rotating sleep pattern |
| ShortNoticeTrips | 1 if the driver was required by his/her carrier to accept short notice trips |
| FillInTrips | 1 if the driver was under pressure by his/her carrier to fill in for other drivers (i.e. perform extra work) when other drivers are absent |
| UnpaidLoading | 1 if the driver was required by his/her carrier to complete uncompensated loading/unloading activities |
| OtherRelations | 1 if there were other carrier relation factors not captured in other carrier relation variables that may have had a bearing on crash occurrence"). |
| Hurrying | 1 if driver was in a hurry prior to crash occurrence. |
| ScheduledExtensions | 1 if the driver experienced work pressure due to his/her carrier scheduling trips in a manner that requires extended work shifts to complete |
| UnscheduledExtensions | 1 if the driver experienced work pressure due to his/her carrier pressing the driver to accept unscheduled loads/trips that require the driver to operate while fatigued |

* Variables incorporated into WorkPressureCount in the original LTCCS DriverAssessment Data Set. (Federal Motor Carrier Safety Administration; U.S. Department of Transportation, 2006a)

Investigators conducting the data collection neither collected nor reported data on compensation level; data collectors erroneously reported that all truck drivers earn the same 'salary' (in the US, the Fair Labor Standards Act prohibits paying production workers a flat salary). Compensation method, however, using the non-public interview data in the IntvwDrDriver Data Set, indicates that 211 out of 854 CDL drivers reported being paid by the mile. MileagePayThisTrip(Driver), an indicator variable created by coding 'by the mile' conservatively as 1 and all other responses ('percent of gross trip revenue, by the hour, other, by the load, not applicable, and unknown'[iv]) as 0 provides a measure that is slightly more robust for unknown reasons than the one created from the non-public IntvwCarrier Data Set on the same attribute. According to the data, 196 CDL drivers were paid percentage of revenue, 276 were paid hourly, and 41 were paid by the load; pay method for 48 drivers is undocumented. Irregularities in data collection and an unrepresentative NASS sampling frame probably explain at least part of the discrepancy, but the extent and direction of bias are unknown. In addition, the same question asked of more than one individual—in this case, the driver and the carrier—shows different answers. My decision to code compensation as mileage-based is conservative in this case because pay 'by the mile' is explicit and specific. Payment by the mile is a clear piecework compensation system.

Control variables that might be expected to contribute to ACR, but do not, are not reported here; they are statistically insignificant. They include 'White' (an indicator variable created from EthnicOrigin); Owner-Operator; all variables related to whether drivers loaded or unloaded freight; and all variables related to whether the company pays drivers to load and/or unload. Because the responses to questions regarding drivers' pay for loading and unloading are contingent on whether they were paid for loading and unloading this trip, and because missing responses on this contingency reduces the *n*, these also are insignificant and cannot be analyzed. Neither detention time nor compensation for detention time were recorded.

## Model and Results

The following model seeks to determine the effects of these work factors on truck crashes.

$$\text{AssignedCriticalReason} = \alpha + \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 + \beta_7 + \beta_8 + \varepsilon$$

where $\beta_1$ = WorkPressureTotal, $\beta_2$ = AggressionCount, $\beta_3$ = Fatigue, $\beta_4$ = ClassYears, $\beta_5$ = ClassYearsSq, $\beta_6$ = SafetyBonus, $\beta_7$ = HoursDriving, $\beta_8$ = MileagePayThisTrip(Driver), and $\varepsilon$ = error.

Descriptive statistics for variables used in the model indicate that the DriverAssessment datasets showed a total of 183 WorkPressure attributes for CDL Truck drivers, distributed across 1,014 CDL truck drivers. LTCCS data coded most truck drivers with only one attribute, but some drivers had more and two drivers had six attributes (Table 2). AggressionCount (from the DriverDecisionAggression Data Set) showed that most drivers were coded with one aggressive act, but four were coded with two. Among CDL drivers, 121 were coded for fatigue (from the DriverAssessment dataset), 154 CDL drivers reported their carrier pays a safety bonus to eligible drivers (from the IntvwDrDriver dataset), and 211 reported that they were paid by the mile (from the IntvwDrDriver dataset). Eleven drivers were coded for work-related Hurrying (from the DriverAssessment dataset). Finally, on average each CDL driver was experienced, with 12.7 years of experience (from the IntvwDrDriver dataset).

**Table 2: Frequency Breakdown of WorkPressureTotal**

Cases selected according to GVE CDL Truck
2284 total cases of which 1276 are missing (including non-trucks)
Total Cases: 1,008

| Group | Count | Cumulative Count | % | Cumulative % |
|---|---|---|---|---|
| 0 | 883 | 883 | 87.599 | 87.599 |
| 1 | 81 | 964 | 8.036 | 95.635 |
| 2 | 25 | 989 | 2.480 | 98.115 |
| 3 | 15 | 1,004 | 1.488 | 99.603 |
| 4 | 2 | 1,006 | 0.198 | 99.802 |
| 5 | 0 | 1,006 | 0 | 99.802 |
| 6 | 2 | 1,008 | 0.198 | 100.000 |

**Table 3: Descriptive Statistics for CDL Truck Drivers**
2,284 cases for which 1,014 are trucks large enough to require a CDL and have been coded AssignedCriticalEvent. Data collectors assigned the critical event or the critical reason for the critical event, or both, to trucks in approximately 50% of all crashes.

| **Attribute** | | **Frequencies** | **Cases** |
|---|---|---|---|
| WorkPressureTotal | | | |
| | NewPosition | 17 | 1,014 |
| | ShippingDeadline | 3 | 1,014 |
| | EXPWorkSchedule | 17 | 1,014 |
| | Quotas | 1 | 1,014 |
| | ExtraLoads | 7 | 1,014 |
| | Demoted | 1 | 1,014 |
| | SelfInducedIllegal | 10 | 1,014 |
| | SelfInducedOther | 25 | 1,014 |
| | OtherPressure | 17 | 1,014 |
| | LoadPressureIndicator | 35 | 1,014 |
| | ShortNoticeTrips | 16 | 1,014 |
| | FillInTrips | 6 | 1,014 |
| | UnpaidLoading | 9 | 1,014 |
| | OtherRelations | 19 | 1,014 |
| WorkPressureTotal | | 183 | |
| AggressionCount | | 55 have one attribute;<br>4 have two attributes | 978 |
| Fatigue | | 121 | 851 |
| SafetyBonus | | 154 | 902 |
| MileagePayThisTrip | | 211 | 854 |
| Hurrying | | 11 | 1,008 |

| **Attribute** | | **Summary Statistics** | |
|---|---|---|---|
| ClassYears | | Mean: 12.7<br>Median: 10<br>Standard Deviation: 11.2 | 857 |
| HoursDriving | | Mean: 4.1<br>Median: 3.7<br>Standard Deviation: 3.3 | 785 |

WorkPressureTotal was tested using a Principal Components Analysis (PCA) instead of Cronbach's Alpha because PCA is more robust to missing data. One of the challenges using the LTCCS is that data collection on non-truck drivers is almost entirely absent, especially on the variables of interest for this analysis. For example, if work pressure is a significant predictor of whether truck drivers are assigned the critical reason for the critical event, and if non-truck vehicles involved in crashes were driven either by people who were working at the time of the crash (e.g., a salesman) or people who were commuting to or from work, or had work problems on their minds, the data do not capture this fact. This asymmetry means that it is impossible to analyse the overall effect of work pressure on crash causation, hence the large number of missing variables (non-trucks). Rather, it only captures the effect of truck drivers' work pressure. In contrast, PCA shows the first-ranked factor has eigenvalues with the same sign, consistent with the existence of a systematic relationship among the variables.

**Table 3: Descriptive Statistics for CDL Truck Drivers**

2,284 cases for which 1,014 are trucks large enough to require a CDL and have been coded AssignedCriticalEvent. Data collectors assigned the critical event or the critical reason for the critical event, or both, to trucks in approximately 50% of all crashes.

| **Attribute** | | **Frequencies** | **Cases** |
|---|---|---|---|
| WorkPressureTotal | | | |
| | NewPosition | 17 | 1,014 |
| | ShippingDeadline | 3 | 1,014 |
| | EXPWorkSchedule | 17 | 1,014 |
| | Quotas | 1 | 1,014 |
| | ExtraLoads | 7 | 1,014 |
| | Demoted | 1 | 1,014 |
| | SelfInducedIllegal | 10 | 1,014 |
| | SelfInducedOther | 25 | 1,014 |
| | OtherPressure | 17 | 1,014 |
| | LoadPressureIndicator | 35 | 1,014 |
| | ShortNoticeTrips | 16 | 1,014 |
| | FillInTrips | 6 | 1,014 |
| | UnpaidLoading | 9 | 1,014 |
| | OtherRelations | 19 | 1,014 |
| WorkPressureTotal | | 183 | |
| AggressionCount | | 55 have one attribute;<br>4 have two attributes | 978 |
| Fatigue | | 121 | 851 |
| SafetyBonus | | 154 | 902 |
| MileagePayThisTrip | | 211 | 854 |
| Hurrying | | 11 | 1,008 |

| **Attribute** | | **Summary Statistics** | |
|---|---|---|---|
| ClassYears | | Mean: 12.7<br>Median: 10<br>Standard Deviation: 11.2 | 857 |
| HoursDriving | | Mean: 4.1<br>Median: 3.7<br>Standard Deviation: 3.3 | 785 |

**Table 4: Principal Component Analysis**
cases selected according to GVE CDL Truck
2284 total cases of which 1270 are missing

EigenValues

| | | Variance |
|---|---|---|
| | Values | Proportion |
| e1 | 2.507 | 27.9 |
| e2 | 1.897 | 21.1 |
| e3 | 1.161 | 12.9 |
| e4 | 0.876 | 9.7 |
| e5 | 0.770 | 8.6 |
| e6 | 0.626 | 7.0 |
| e7 | 0.459 | 5.1 |
| e8 | 0.393 | 4.4 |
| e9 | 0.311 | 3.5 |

EigenVectors

| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 |
|---|---|---|---|---|---|---|---|---|---|
| ShippingDeadline_m | -0.310 | 0.510 | 0.020 | 0.189 | -0.078 | -0.045 | -0.307 | -0.575 | -0.419 |
| EXPWorkSchedule_m | -0.278 | -0.003 | 0.485 | -0.671 | 0.057 | -0.422 | -0.225 | 0.072 | 0.024 |
| Quotas_m | -0.185 | 0.540 | -0.203 | 0.154 | -0.372 | -0.215 | -0.165 | 0.493 | 0.392 |
| ExtraLoads_m | -0.384 | -0.316 | -0.402 | 0.108 | 0.031 | -0.411 | 0.109 | 0.316 | -0.546 |
| LoadPressureIndicator_m | -0.427 | -0.134 | 0.330 | 0.140 | -0.007 | 0.646 | -0.284 | 0.385 | -0.157 |
| UnscheduledExtensions_m | -0.328 | -0.273 | -0.203 | -0.291 | -0.700 | 0.198 | 0.206 | -0.311 | 0.153 |
| ScheduledExtensions_m | -0.337 | -0.119 | 0.495 | 0.524 | 0.009 | -0.279 | 0.432 | -0.136 | 0.263 |
| ShortNoticeTrips_m | -0.413 | -0.174 | -0.394 | 0.002 | 0.508 | 0.027 | -0.289 | -0.226 | 0.501 |
| FillInTrips_m | -0.267 | 0.460 | -0.103 | -0.316 | 0.322 | 0.264 | 0.650 | 0.082 | -0.068 |

Unrotated Factor Matrix

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
|---|---|---|---|---|---|---|---|---|---|
| ShippingDeadline_m | -0.491 | 0.703 | 0.022 | 0.177 | -0.068 | -0.036 | -0.208 | -0.360 | -0.233 |
| EXPWorkSchedule_m | -0.439 | -0.004 | 0.523 | -0.628 | 0.050 | -0.334 | -0.152 | 0.045 | 0.013 |
| Quotas_m | -0.293 | 0.744 | -0.219 | 0.144 | -0.326 | -0.170 | -0.112 | 0.309 | 0.218 |
| ExtraLoads_m | -0.608 | -0.435 | -0.434 | 0.101 | 0.027 | -0.325 | 0.074 | 0.198 | -0.304 |
| LoadPressureIndicator_m | -0.677 | -0.185 | 0.356 | 0.131 | -0.006 | 0.511 | -0.192 | 0.242 | -0.088 |
| UnscheduledExtensions_m | -0.520 | -0.376 | -0.219 | -0.272 | -0.614 | 0.157 | 0.140 | -0.195 | 0.085 |
| ScheduledExtensions_m | -0.534 | -0.163 | 0.533 | 0.491 | 0.008 | -0.221 | 0.293 | -0.085 | 0.147 |
| ShortNoticeTrips_m | -0.653 | -0.240 | -0.425 | 0.002 | 0.445 | 0.022 | -0.196 | -0.142 | 0.279 |
| FillInTrips_m | -0.422 | 0.633 | -0.111 | -0.296 | 0.282 | 0.209 | 0.440 | 0.052 | -0.038 |

A GLM (general linear model) analysis for AssignedCriticalReason uses logistic regression to estimate the model and the coefficients. The model predicts whether the truck driver would be assigned the 'critical reason for the critical event' that led to the crash. OLS ANOVA demonstrates that all the variables in the model have significant predictive value, including both continuous variables (AggressionCount, ClassYears, HoursDriving, and WorkPressure) as well as discrete variables (Fatigue, IDRSafetyBonus, and MileagePayThisTrip[Driver]). The LogLikelihood of this model is -430.81855, which is significant, and it converges in five iterations. All variables are significant individually with high F-ratios, again for both continuous and discrete variables. Coefficients produced by this model are all significant, as expected, and the Wald test is appropriate for small coefficients. Scheffe post-hoc tests yield the same results and are significant. Calculating the predicted values from the logistic regression and then calculating the correlation between the predicted values and the dependent variable allows the derivation of the model fit. The Pearson Product-Moment Correlation, 0.383, is squared to obtain the $R^2$ of 14.75% (Table 5).

**Table 5: General Linear Model for Assigned Critical Reason**
Type of analysis: Logistic; ANOVA
Cases selected according to GVE CDL Truck
2284 total cases of which 1574 cases are missing (including non-trucks)
$R^2$: 14.75%

| Iteration | LogLikelihood | Convergence |
|---|---|---|
| 1 | -433.26054 | ————————— |
| 2 | -430.86683 | 0.11826015 |
| 3 | -430.81859 | 0.01815587 |
| 4 | -430.81855 | 0.00055343 |
| 5 | -430.81855 | 0.00000058 |

| Source | df | Sums of Squares | Mean Square | F-ratio | P-value |
|---|---|---|---|---|---|
| Intercept | 1 | 18.1651 | 18.1651 | 18.198 | ≤ 0.0001 |
| AggressionCount* | 1 | 15.1209 | 15.1209 | 15.148 | 0.0001 |
| Fatigue** | 1 | 30.4849 | 30.4849 | 30.539 | ≤ 0.0001 |
| ClassYears* | 1 | 9.04029 | 9.04029 | 9.0565 | 0.0027 |
| IDRSafetyBonus** | 1 | 8.74275 | 8.74275 | 8.7584 | 0.0032 |
| HoursDriving* | 1 | 12.0612 | 12.0612 | 12.083 | 0.0005 |
| WorkPressureTotalD* | 1 | 8.99809 | 8.99809 | 9.0142 | 0.0028 |
| MileagePayThisTrip(Driver)** | 1 | 5.37788 | 5.37788 | 5.3875 | 0.0206 |
| Error | 702 | 700.746 | 0.998213 | | |
| Total | 709 | 786.266 | | | |

* Continuous ** Discrete

Coefficients of AssignedCriticalReason for Continuous Variables

| Covariate | Coefficient | std. err. | Wald | p-value |
|---|---|---|---|---|
| Level of Intercept | 0.8318 | 0.2420 | 11.82 | 0.0006 |
| AggressionCount | 1.484 | 0.3817 | 15.12 | 0.0001 |
| ClassYears | -0.0231 | 7.693e-3 | 9.040 | 0.0026 |
| HoursDriving | -0.0974 | 0.0281 | 12.06 | 0.0005 |
| WorkPressureTotal | 0.5822 | 0.1941 | 8.998 | 0.0027 |

Coefficients of AssignedCriticalReason for Discrete Variables

| Covariate | Coefficient | std. err. | Wald | p-value |
|---|---|---|---|---|
| Fatigue | 0.9145 | 0.1656 | 30.48 | ≤ 0.0001 |
| IDRSafetyBonus | -0.3187 | 0.1078 | 8.743 | 0.0031 |
| MileagePayThisTrip(Driver) | -0.2245 | 0.0968 | 5.378 | 0.0204 |

Scheffe Post Hoc Tests

| Covariate | Difference | std. err. | P-value |
|---|---|---|---|
| Fatigue | 1.82900 | 0.3310 | 0.000000 |
| IDRSafetyBonus | -0.637436 | 0.2154 | 0.003186 |
| MileagePayThisTrip(Driver) | -0.448953 | 0.1934 | 0.020567 |

Coefficients for the independent variables replace the betas in the equation above:

AssignedCriticalReason for the critical event = 0.8318+ (0.5822)WorkPressureTotal +
(1.484)AggressionCount + (0.9145)Fatigue + (-0.0231)ClassYears +
(-0.3187)IDRSafetyBonus + (-0.0974) HoursDriving +
(-0.2245)MileagePayThisTrip(Driver) + $\varepsilon$

Interpretation of the foregoing results indicates the extent to which the presence of '1' in the dependent variable (that is, the data collectors' assignment of the critical reason for the critical event to the truck) is associated with the independent variables that predict this assignment. That is, every assignment of the critical reason to the truck is associated positively and significantly with WorkPressureTotal, AggressionCount, and Fatigue, according to the coefficients reported above. Every assignment of the critical reason to the truck is associated negatively and significantly with ClassYears, SafetyBonus, HoursDriving (this trip, since an eight-hour break), and MileagePayThisTrip(Driver), according to the coefficients reported above.

In other words, more work pressure, more driver aggressiveness, and more fatigue are associated with a finding that the truck driver's action led to the crash. On the other hand, greater years of experience in that class of truck, payment of a safety bonus, the number of hours of driving during the trip in which the crash occurred, and pay by the mile ('piecework') offset the preceding effects. The three most salient work-pressure attributes — work pressure, driver aggression, and fatigue — have the strongest effects on outcomes. While arguably driver aggressiveness and fatigue could be due to non-work factors, the context of these attributes, associated with being in a hurry and having a strenuous and demanding job, suggests that work-related pressures contribute significantly to crashes.

The negative work-related attributes with paradoxical results, HoursDriving and MileagePayThisTrip(Driver), may be noisy because HoursDriving is merely the elapsed time between when the driver began the crash trip and when the crash occurred, and MileagePayThisTrip(Driver) reflects the driver interview only. In other words, the 'hours driving' variable is attenuated by the fact that the reported number of hours truncates at the time of the crash and does not represent driving hours generally performed by the CMV driver. Prior research, as well as intuition, would suggest that 'mileage pay this trip' should predict a greater crash likelihood. Both may have negative signs because they reflect only reported circumstances (hours driving and payment structure) associated with the most recent trip. Because almost all over-the-road drivers are paid by the mile or on another contingent basis (as discussed above), and because measurement of the pay concept is so weak in the LTCCS, the negative sign on the variable may just proxy the distinction between long-distance work and local work, for which the LTCCS has no measure. Most local truck and bus driving is paid by the hour.

## Conclusion

Previous research has shown that human capital and labor market factors are very important predictors of truck crashes, which reflects on wage levels (Rodriguez, 2003; Rodriguez, 2006). This exploratory analysis supports previous findings that work organization, economic pressure, and compensation directly affect safety. In the logistic regression used for this analysis, factors embedded within the regression suggests that these contributing factors are significant, particularly when considered as a system, as is the employment relationship in organized business activity within a service market. In other words, crash causation analysis makes sense only within an economic framework in which CMV drivers perform their activity in a mobile workplace. These work-pressure factors, which were created from variables that are marginally significant individually, are highly significant when combined into a single factor, supporting their use in an index in this model. Most research on truck crashes fail to fully engage the economic pressures underlying the activity that led to the crash.

Economic theory predicts that driver quality — including individual driver characteristics associated with safety — is directly related to the human capital of the worker, and compensation is the ideal proxy for human capital within a market (Abowd et al., 2005; Becker, 1975) In addition, pressure exerted on workers by their employers, their customers, or by the collective pressure of the market itself (which includes pressure on individuals), clearly influences the driver's safety. Though this analysis does not determine the causes of fatigue and driver aggressiveness here, these findings suggest they are associated with work-related pressures.

These results further suggest that efforts on the part of regulators to create and reinforce an environment conducive to reducing the stresses that cause fatigue and aggressiveness will help to reduce crashes. Such efforts might include strict regulations limiting hours of work or, more effectively, creating an enforceable minimum wage in trucking that sets such a wage at a rate conducive to safety, including pay for all non-driving labor. Belzer and Sedo (2018) suggest that a safe mileage rate, in the United States, would be around 60 cents per mile, which is approximately 50% greater than the current average rate. Evidence in this study and elsewhere, which suggests that truck drivers systematically log unpaid non-driving labor off duty, implies that policy-makers could achieve greater compliance with hours-of-service regulation and greater safety by mandating that motor carriers and ultimately cargo owners pay truckers for their non-driving work time. Indeed, a study of detention time by the Office of the Inspector General of the U.S. Department of Transportation shows that truck drivers detained beyond two hours' loading or unloading have a significant crash risk. Even after ignoring the first two hours of such labor time (for which most drivers earn little or no compensation), an additional fifteen minutes of delay is associated with a 6.2% increase in the average expected crash rate (Office of the Inspector General - U.S. Department of Transportation, 2018). Since approximately 25% of all driver labor time is unpaid non-driving labor, this is a major influence on safety. This exploratory analysis using the Large Truck Crash Causation Study data therefore confirms that these factors are strongly related to truck safety, but further data collection designed to remedy the flaws in the LTCCS is needed to examine these factors in more depth.

Specifically, this study shows that pressure on truck drivers exerted by work organization and competitive market intensity predict 15% of truck crash probability, separate from the level of compensation, which LTCCS did not collect. The lack of reliable information on compensation level in the LTCCS data does not allow researchers to incorporate both pay rates and work pressure into the same model, so further research is needed to establish this link definitively. Research has shown, however, the connection between wage levels and safety (Rodriguez, 2003; Rodriguez, 2006). In addition, because pay rates predict the number of hours truck drivers will work (Belzer, 2018), and because drivers are more likely to have crashes as their hours of work increase (Jovanis, 2005), this research contributes to a body of scholarly work showing the connection between economic pressures and highway safety. Public policy that encourages truck drivers to work excessive hours, with intense performance pressure, will continue to contribute to highway safety risk. A conservative conclusion based on the LTCCS shows that at least 15% of truck crash probability can be predicted from economic factors associated with the work process alone, independent of compensation; a reduction in these risk factors will reduce crashes. A carefully designed survey in which key economic factors that might predict crashes are identified and collected would provide a sound basis on which to determine the extent to which such factors contribute to truck crashes.

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## Author biography

Michael H Belzer, an associate professor in the economics department at Wayne State University, is an internationally recognised expert on the trucking industry, especially the institutional and economic impact of deregulation. He is the author of *Sweatshops on Wheels: Winners and Losers in Trucking Deregulation* (Oxford University Press, 2000). He has written many peer-reviewed articles on trucking industry economics, labour, occupational safety and health, infrastructure, and operational issues, and initiated a strategic economic development plan to transform Southeast Michigan into a global freight transportation hub.

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[i] Truck drivers and their employers make a joint decision to work more hours and research has not disentangled the actors in this joint choice.

[ii] See LTCCS Codebook' (FMCSA, 2006b: 1) and 'LTCCS Analytical Users Manual' (FMCSA, 2006a: 632) for supporting documentation.

[iii] Attributes are not weighted because weights would be speculative.

[iv] The codebook says drivers paid both by the mile and the hour are coded '44' but the data set does not include any such coded drivers.