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Predicting interstate motor carrier crash rate level using classification models

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ABSTRACT

Ensuring safe operations of large commercial vehicles (motor carriers) remains an important challenge, particularly in the United States. While the federal regulatory agency has instituted a compliance review-based rating method to encourage carriers to improve their safety levels, concerns have been expressed regarding the effectiveness of the current ratings. In this paper, we consider a crash rate level (high, medium, and low) rather than a compliance review-based rating (satisfactory, conditional satisfactory, and unsatisfactory). We demonstrate an automated way of predicting the crash rate levels for each carrier using three different classification models (Artificial Neural Network, Classification and Regression Tree (CART), and Support Vector Machine) and three separate variable selection methods (Empirical Evidence, Multiple Factor Analysis, Garson's algorithm). The predicted crash rate levels (high, low) are compared to the assigned levels based on the current safety rating method. The results indicate the feasibility of crash rate level as an effective measure of carrier safety, with CART having the best performance.

1. Introduction

In the United States (U.S.), large truck crashes are a leading cause of death and injuries every year, and result in billions of dollars in medical expenses and productivity loss. There are ongoing efforts at the federal and carrier level to help enhance the safety performance of all motor carriers. However, many safety management systems do not appear to be effective (Mooren et al., 2014). For that reason, it is important to identify the key indicators of safe commercial vehicle operations, which would lead to an effective classification of carrier safety levels.

The U.S. Department of Transportation (DOT) Federal Motor Carrier Safety Administration (FMCSA) conducts on-site compliance reviews of motor carrier operations based on several criteria that include the drivers' service hours, driver qualifications, maintenance and inspection records, and crash reports (Chen, 2008). The motor carriers are then assigned a unique safety rating. However, concerns have been expressed that, "the overall conclusion is that the worse a firm does on a large part of the audit, the better its accident record" (Moses and Savage, 1992). In fact, some of the studies on the effectiveness of the safety audits reveal that some inspection activities are unrelated to the actual safety performances of the motor carriers (Moses and Savage, 1992, 1994).

FMCSA has created the Compliance, Safety, Accountability (CSA) program, a data-driven safety compliance and enforcement program to improve safety and prevent commercial motor vehicle crashes, injuries, and fatalities (Volpe, 2013). This program includes data analyses generated from the original MCMIS dataset to identify non-compliant and unsafe companies to prioritize them for enforcement interventions. The Safety Measurement System (SMS) is a key component of CSA, which uses data from inspections and crash reports to identify and intervene with motor carriers that pose the greatest risk to safety. Many of the concepts used to construct the SMS originated from the SafeStat measurement system. SafeStat was developed under a project plan agreement with the Federal Highway Administrations (FHWA) Office of Motor Carriers, FMCSAs predecessor. It was designed and tested under the Federal/State Performance and Registration Information Systems Management (PRISM) program in the mid-1990s. From the mid-1990s until December 2010, when FMCSA replaced SafeStat with the SMS, SafeStat was implemented nationally to prioritize motor carriers for on-site compliance reviews (Volpe, 2013).

CSA organizes the data into seven Behavior Analysis and Safety Improvement Categories (BASICs). The SMS groups carriers by BASICs with other carriers that have a similar number of safety events and then assigns a percentile to prioritize them for interventions (Volpe, 2013).

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However, some studies show that BASICs are not always effective. For example, Lueck (2012) show that as a carriers' Driver Fitness record improves, its crash rate goes up.

Crashes involving commercial vehicles have greater severity, in terms of injuries and cost, than that of passenger vehicles (Blincoe et al., 2015). Rogers and Knipling (2007) showed that 48% of truck crashes that involved fatalities and injuries were not necessarily due to the faults of the commercial drivers. The study showed that in fatal crashes that involve a truck and a passenger vehicle, 44% of the truck drivers and 56% had a critical reason assigned to the other vehicle or driver. The Driver/Carrier Data Relationship Project showed that drivers with high citation rates were positively correlated with high crash rates (Murray et al., 2005).

Knipling (2009) also found major differences for the CRs assigned to the truck drivers between single-vehicle truck crashes and multiple-vehicle truck crashes. In single-vehicle truck crashes, speed, fatigue, vehicle failure and inattention were the most important factors, whereas in multiple-vehicle crashes, inattention, inadequate surveillance, speed, and illegal maneuvers were most important. Data from the Large Truck Crash Causation Study (LTCCS) showed that 87% of crashes were caused by driver errors (Federal Motor Carrier Safety Administration, 2006a).

Findings from many carrier-based studies have been based on logistic regression models. Lantz and Loftus (2005) used a logistic regression model to examine the association between driver violations and carrier crash rates, and Blower and Green (2009) used this modeling technique with LTCSS data to show that vehicle defects (brakes, tires, steering) were significantly associated with crash events as they could negatively impact the ability of the driver to respond appropriately. They also showed that the maintenance of large trucks were an important contributor to large truck crashes.

The Motor Carrier Management Information System (MCMIS) dataset has also been used to identify predictors of crash rates, mostly using Poisson regression (Moses and Savage, 1992), negative binomial regression (Moses and Savage, 1994), and ordinary least squares (OLS) (Corsi et al., 1984; Corsi and Fanara, 1988a,b). The negative binomial is often preferred given the over-dispersed nature of the crash data. All of these models belong to the category of generalized linear models (GLMs). However, based on the FMCSA compliance reviews and crash rates, the motor carriers may be more appropriately categorized into subgroups, which lends itself to a classification rather than a regression approach. In recent years, models such as classification trees, support vector machines, and artificial neural networks have been used to successfully classify large and heterogeneous datasets comprising both continuous and discrete or categorical variables. By learning suitable model parameters and structures, they have been effective in many challenging computer vision, natural language processing, and user behavior detection applications. In this study, we consider the potential of classifying the safety outcomes of motor carriers using the MCMIS dataset, which assigns a unique safety rating for each carrier based on the U.S. DOT FMCSA compliance review. The research objective is, therefore, to examine the suitability of classification models in predicting carrier safety.

2. Materials and methods

2.1. Datasets

The MCMIS dataset assigns a unique safety rating for each carrier based on the U.S. DOT FMCSA compliance review (Federal Motor Carrier Safety Administration, 2017). The safety rating consists of three levels: satisfactory (S), conditional satisfactory (C), and unsatisfactory (U). Although not perfect, this rating provides information on the safety performance of the carriers. This database contains detailed records of all the reported crash events, census studies, and inspection results.

The Carrier Safety Measurement System (CSMS) is another system that serves as a potential carrier safety identification tool. There are four tables used in this study: three are from MCMIS (REVIEW, CENSUS and CRASH_MASTER) and one is from CSMS (CARRIER).

The CRASH_MASTER table contains 70 data elements for 3,022,849 crash events from 1989 to 2015. After removing all the crash events with missing DOT numbers, 2,073,489 events are available for a total of 410,259 different motor carriers. The data elements include the location and time of any specific crash event, basic information of the vehicles involved in the crash, environmental condition (weather, road, etc.) of the crash event, detailed information about the reporting process, and injuries and fatalities associated with the crash event. 12 of these elements are of interest to us, which include the severity of the crash, configurations of the crash vehicles, and environmental conditions. Detailed data element names and definitions are available at https://ask.fmcsa.dot.gov/app/mcmiscatalog/d_crash3 (see Table A.11 in Appendix). Because of the size of the dataset, all crash events with missing fields are eliminated. After removing the missing values, there are 1,274,472 crash events related to 293,788 motor carriers.

The REVIEW table contains information on the compliance review, which is then used for the FMCSA designated safety ratings of the carriers. Three (3) safety ratings are listed in the MCMIS database: overall rating (RATING_OVERALL), provisional rating (PROVISIONAL_RATING), and safety rating (SAFETY_RATING). Little information is available for the provisional rating. Hence, RATING_OVERALL and SAFETY_RATING is considered for the subsequent analysis.

The review dates for these ratings vary from 1987 to 2010. The overall rating is available only until 2002, at which time it is no longer collected. Fig. 1a shows the percentage of carriers in each overall rating level from 1990 to 2001. Compared to the overall rating, the safety rating is maintained up to the most recent years, and is, thus, more useful for our purpose. Fig. 1b shows the percentage of carriers in each safety rating level from 2003 to 2010. Both figures show that the proportion of carriers in the different rating levels remain more or less stable over the observed time periods.

The CENSUS table contains the carrier operation types; this includes interstate carriers, intrastate carriers transporting hazardous materials, and intrastate carriers transporting non-hazardous materials. In total, there are 2,464,729 motor carriers with unique operations. 61.9% (n = 1,525,993) of the carriers provide interstate services, and the other 38.1% (n = 938,736) provide intrastate services, of which 96.7% (n = 908,207) are involved in non-hazardous materials transportation.

The CARRIER table contains the average power units for each motor carrier and is defined as the weighted averages of the power units as reported six (6) months and eighteen (18) months prior to the snapshot date FMCSA (2018). This variable is used as a measure of carrier size. There are 1,640,195 carriers in this table.

After preprocessing, a training dataset is constructed from the four tables by merging the unique DOT numbers for each motor carrier. After merging, the crash events of the most recent 6 years (from 2010 to 2015) is pulled out and the crash rate levels are assigned. As noted earlier, there is no overall rating as of 2002. We also note that the safety rating does not change substantially from 2003 to 2010. Both of the ratings follow a stable trend for different compliance levels. Therefore, it is reasonable to assume that the percent of carriers in different safety levels do not change much in the observed years. For overall rating, the average percent is 55.2% for S, 30.4% for C, and 14.4% for U. For safety rating, the corresponding average percents are 67.5%, 27.1%, and 5.4% for S, C, and U, respectively. Moving forward, the accuracy of the predictions for the crash rate levels will be based on SAFETY_RATING given that more recent data is available.

2.2. Calculating crash rates

We hypothesize that using the crash rate levels is a better indicator of carrier safety since it captures the actual crash rate characteristics. The crash rate of a carrier is defined in Eq. (1). We note here that a