

Using CHAID Decision Trees to Evaluate Severities of Missouri Truck Crashes

Final Report
June 2018

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16. Abstract Large truck transport is vital for freight shipping in the United States; yet, it can prove to be a dangerous mode of transportation. From 2002 to 2012, 91,145 crashes involving large trucks occurred in Missouri, resulting in 1,156 fatalities and 18,457 injuries. Many factors contribute to large-truck crash severity, and it is theorized that these factors and their effect on injury severity vary as a function of gender. Missouri traffic and personal and vehicle crash data from 2002 to 2012 were used to analyze situations that increase the probability of injuries and fatalities, given a large-truck crash occurs. Chi-squared automatic interaction deduction (CHAID) decision trees were developed to predict values of injury severity based on environmental factors, contributing circumstances, and gender, to better understand predictor importance and uncover interactions among factors. Results suggest that the major contributory predictors for crash severity for Missouri female drivers include: driving too fast for conditions, driving on the wrong side of the road, improper backing, speeding, and improper turning. Major contributing predictors for Missouri male drivers include: driving too fast for conditions, improper backing, violation of stop sign or signal, improper turning, and failing to secure loads. Additional results suggest that, when speeding, the probability for a fatality is 14.29% for Missouri female commercial driver's license (CDL) drivers and an injury is 28.57%, given a crash occurs. For Missouri male CDL drivers, when driving too fast for conditions on the wrong side of the road, an 8.70% and 48.91% probability for fatality and injury exists, respectively. Therefore, the researchers recommend that truck driver training programs focus on gender-specific behaviors that impact crash injury severity in order to enhance road safety measures.					
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TABLE OF CONTENTS

ACKNOWLEDGMENTS	vii
INTRODUCTION	1
PRIOR RESEARCH.....	2
DATA	3
METHODOLOGY	6
CONCLUSIONS.....	12
LIMITATIONS AND FUTURE RESEARCH.....	13
REFERENCES	15

LIST OF FIGURES

Figure 1. Predictor importance for crash severity for male CDL drivers	7
Figure 2. Predictor importance for crash severity for female CDL drivers	7
Figure 3. CHAID Results for male CDL drivers when driving too fast for conditions is present	8
Figure 4. CHAID results for male CDL drivers when driving too fast for conditions is not present	9
Figure 5. CHAID results for female CDL drivers	11

LIST OF TABLES

Table 1. Frequency of crashes by driver licensing state	3
Table 2. Frequency of crash severity by driver gender	4
Table 3. Frequency of crash injury severity by contributing circumstance	5

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INTRODUCTION

Large truck transport is a vital medium for freight in the United States; yet, it can prove to be a dangerous mode of transportation for both people and cargo. In a 10-year time span, roughly 400,000 crashes involving large trucks in the United States occurred, with 12% of these collisions killing at least one person and injuring over 1,000 each year (Javers and Schlesinger 2014). Moreover, approximately 4,000 people are killed on average each year in crashes involving large trucks, which is equivalent to a regional jet crashing and killing everyone on board each week of the year (Javers and Schlesinger 2014). Consequently, the fatalities and injuries resulting from large-truck crashes are a major problem that needs to be addressed for the future of traffic safety. To do this, the underlying causes of truck crashes and truck crash injuries must be explored.

Many factors contribute to large truck crash injury severity, and it is theorized that these factors and their effect vary as a function of gender. The existing body of literature solidifies merit for research on the link between driver gender and crash injuries when large trucks are involved. It has been reported that the risk of a fatality for female drivers age 20 to 35 is 28% higher than similarly aged male drivers, with this trend continuing to include non-fatal crashes (Obeng 2011). Females are more often involved in side incursion crashes than males (Swedler et al. 2012), and males believe themselves to be better drivers than other motorists in general, while female drivers do not share this same confidence (DeJoy 1992).

With the trucking industry roughly 35,000 drivers short as of 2010, there is a push to recruit and train new drivers (Carey 2010). The recognition of the differing behavioral factors affecting injury severity provide an opportunity for the enhancement and revision of educational and safety standards, especially in new truck driver training programs or curricula. The current recruitment push would be an excellent time to implement enhanced training practices to take advantage of the current knowledge in driver differences and how those differences' impact behavior. New practices and policies stemming from this research have the potential to save thousands of lives over the next few decades.

PRIOR RESEARCH

Much research has been conducted as a result of the devastating effects caused by collisions with large trucks (Zhu and Srinivasan 2011, Islam and Hernandez 2012, Bunn et al. 2013, Islam and Hernandez 2013, Kin et al. 2014, Choi et al. 2014, Islam et al. 2014, Islam and Hernandez 2014). For example, Zhu and Srinivasan (2011) developed ordered probit regression models to describe the likelihood of crash severity using data derived from the Large Truck Crash Causation Study conducted by the Federal Motor Carrier Safety Administration and National Highway Traffic Safety Administration. Considering human, vehicle, crash, and environmental characteristics, it was concluded that the greatest dangers in truck crashes resulted from opposing traffic situations, such as those at intersections and from lack of driver familiarity with their vehicle (Zhu and Srinivasan 2011). The researchers proposed that increased driver training and vehicle familiarization and better traffic separation at opposing situations would mitigate the overall injury severity of large-truck crashes (Zhu and Srinivasan 2011). Islam and Hernandez (2013) also employed ordered probit models to classify the injury severity of large-truck crashes and found interaction effects between human-factor and vehicle-factor variables. The researchers suggested that additional research was needed to improve truck driver training (Islam and Hernandez 2013).

Focusing on gender differences, Amarasingha and Dissanayake (2014) developed Poisson regression and negative binomial regression models to evaluate the impact of highway engineering factors, such as rumble strips and lane widths, on truck crash frequencies in Kansas and concluded that females are likely to be involved in fewer automobile crashes than males. Similarly, Cantor et al. (2010) tested various factors' effects on the likelihood of future crash involvement using data derived from the Federal Motor Carrier Safety Administration, with results indicating that the likelihood of a crash is significantly different for male and female truck drivers. Obeng (2011) employed ordered logit models to assess gender differences and injury probability in relation to airbag deployment and concluded that females render a higher risk for injury than males if the airbag is deployed. Recently, Guest et al. (2014) analyzed the effects of gender differences on the crash rate of professional drivers using a negative binomial regression model, with results suggesting major gender differences on the effect of seatbelt use, airbag deployment, and driver condition on the risk of injury severity. It was concluded that customization of safety features should apply to gender and additional research in this area should be conducted.

Responding to the call for additional research that focuses on large-truck crash severity in order to customize gender specific safety features and improve truck driver training, this study analyzes circumstances that increase the probability of injuries and fatalities for male and female commercial driver's license (CDL) drivers.

DATA

The State of Missouri has stringent expectations for its commercial drivers. The *Missouri Commercial Driver's License Manual* includes information regarding vehicle type, permit requirements, vehicle operations, road maneuvers, and examination information (Missouri Department of Revenue 2016). After content review, drivers undergo a written test specific to the class of license sought. Upon successful completion, a road test that examines vehicle operation capabilities under varying conditions and driving situations, including parking, backing, merging into interstate traffic, driving through intersections, crossing railroad grades, stopping and starting, and driving in traffic in both rural and urban areas is required (Missouri Department of Revenue 2016). Ideally, drivers who successfully pass the examination process are proficient at operating their vehicles in a safe manner on Missouri roadways.

To assess the proficiency of CDL drivers on Missouri roadways, data was obtained from the Missouri State Highway Patrol and contains information for drivers involved in large-truck crashes from 2002 to 2012. Variables include driver characteristics, road conditions, weather conditions, temporal factors, contributing circumstances, and crash injury severity. Injury severity is categorized on a three-class system: Fatality (1), Injury (2), and Non-Injury (3) and is determined from the most severely injured victim of the crash occurrence.

Examination of the data suggests that in Missouri at least 91,145 crashes involving at least one CDL driver of a large truck (e.g., single-unit truck with two or more axles, truck tractors, or other heavy trucks) occurred from 2002 to 2012. Table 1 provides the frequency and percentage of crashes by driver licensing state for the most cited states.

Table 1. Frequency of crashes by driver licensing state

State	Frequency	Percent
Missouri	52,651	57.8
Illinois	7,229	7.9
Kansas	3,882	4.3
Texas	3,002	3.3
Arkansas	2,123	2.3
Iowa	2,021	2.2

The 52,651 truck crashes in Missouri resulted in 1,156 fatalities, where Missouri CDL drivers were involved in 629 of these fatalities. Female CDL drivers were involved in 26 of crashes, with Missouri female CDL drivers involved in seven fatal crashes. Additionally, large-truck crashes in Missouri resulted in 18,457 injuries, where Missouri CDL drivers were involved in 10,887, and Missouri female CDL drivers were involved in 282 of these injuries.

Considering then only crashes involving a Missouri CDL driver, the frequency of crash severity occurrences by driver gender is provided in Table 2.

Table 2. Frequency of crash severity by driver gender

Gender	Crash Severity			Total
	Fatality	Injury	Property Damage	
Male	622	10,601	39,972	51,195
Female	7	282	1,042	1,331
Unknown	0	4	115	119
Total	629	10,887	41,129	52,645
Missing	—	—	—	6

In Missouri in 2014, 233,248 males held CDLs and 25,679 females held CDLs (Missouri Department of Revenue 2014). Interestingly, from 2002 to 2012, 87,962 male and 2,980 female CDL drivers were involved in crashes. The proportion of crashes to number of CDL license holders in Missouri was 37.7% and 11.60% for male and female drivers, respectively. Additionally, on a national scale, 19,561 fatal truck crashes occurred from 2008 to 2012, with female drivers involved in 314 of these fatal crashes (Federal Motor Carrier Safety Administration 2012). This proportion (1.6%) is similar to the Missouri proportion of 1.1% for female drivers involved in fatal crashes.

To better understand the underlying factors that contribute to crash injury severity, specific contributing circumstances were analyzed. After a crash occurs, circumstances contributing to the crash as determined by the investigating officer is selected from the following: vehicle defects, improperly stopped on the roadway, driving at speeds that exceeded the limit, driving too fast for conditions, improperly passing, violating a signal or sign, driving on the wrong side of the road when not passing, following too closely, improper signaling, improper backing, improper turning, improper lane usage or change, driving the wrong way on a one-way, improper start from park, improperly parked, failed to yield, alcohol intoxication, drug intoxication, physical impairment, distracted/inattentive, vision obstructed, animal(s) in roadway, other, and unknown; additionally, driver fatigue/asleep, failed to dim lights, failed to use lights, improper towing/pushing, overcorrected, improper riding, failed to secure load/improper loading, and object/obstruction in roadway were added to the STARS database in 2012.

Table 3 provides the frequency of crash injury severity by contributing circumstances.

Table 3. Frequency of crash injury severity by contributing circumstance

Contributing Circumstance	Crash Severity			Total
	Fatality	Injury	Property Damage	
Vehicle Defects	27	696	3,971	4,694
Improperly Stopped	6	62	227	295
Speeding	13	90	101	204
Too Fast for Conditions	94	1,935	3,751	5,780
Improper Passing	6	137	587	730
Violating Stop Sign / Signal	15	363	532	910
Wrong Side	34	281	634	949
Following Too Close	33	1,617	3,710	5,360
Improper Signal	0	27	112	139
Improper Backing	4	159	3,552	3,715
Improper Turn	7	322	4,546	4,875
Improper Lane Usage	80	1,635	7,327	9,042
Wrong Way (One-Way)	1	8	46	55
Improper Start from Park	1	9	129	139
Improperly Parked	0	13	77	90
Failed to Yield	44	1,137	3,000	4,181
Alcohol	2	65	84	151
Drugs	2	20	26	48
Physical Impairment	20	344	462	826
Distracted/Inattentive	128	2,958	13,599	16,685
Vision Obstructed	37	811	4,812	5,660
Driver Fatigue	1	20	24	45
Failed to Dim Lights	0	1	0	1
Failed to Use Lights	0	1	0	1
Improper Towing / Pushing	0	0	9	9
Overcorrected	2	22	48	72
Improper Riding	0	0	1	1
Failed to Secure Load	0	7	148	155
Animals in Roadway	0	12	100	112
Object in Roadway	0	6	53	59
Other	2	30	239	271
Total	559	12,788	51,907	65,254

Total number of cases does not equal the sum of the frequency of contributing circumstances, since more than one circumstance may be present in a given crash.

METHODOLOGY

While recent research has analyzed large truck crash severity, relatively few studies have employed decision trees as the methodological tool. Using data derived from the Fatality Analysis Reporting System, Solomon et al. (2006) developed decision tree models to identify interacting factors that impact crashes at red light-controlled intersections. The authors claimed that this methodological approach was useful in evaluating the effectiveness of cameras at signaled intersections (Solomon et al. 2006). Eustace et al. (2014) also developed decision tree models to identify interactions between explanatory variables and crash severity. Important interactions identified by the decision tree model suggested that females on higher posted speed limits have higher risk of injury; males with drug involvement at a higher posted speed limit have a higher risk of injury; alcohol use on a road with speed limits over 40 mph have higher risk of injury; and male drivers in crashes on wet road surfaces have higher risk of injury. The authors concluded that not only does the decision tree model analysis identify significant factors of injury severity, it also allows for the detection of multi-level complete interactions.

Even though little research has employed such an approach, Abdel-Aty and Keller (2005) claimed that tree-based regression improves the understanding of the importance of specific factors on individual levels of severity, Oh (2006) concluded that additional research in this area is necessary, and Abay (2013) called for alternative model specification for injury severity analysis.

Chi-squared automatic interaction deduction (CHAID) decision tree models are used to predict values of crash injury severity based on the contributing circumstances indicated previously. The decision tree model is organized in a hierarchical structure that consists of a root node, internal nodes and leaves, and partitions the data set into smaller, more homogenous groups that allow for complex patterns to be uncovered. CHAID decision trees create wider, non-binary trees often with many terminal nodes connected to a single branch and prune the decision tree to mitigate over-fitting of the model (Bayam et al. 2005).

CHAID trees are used to examine cases selected from the STARS database, which adheres to the following criteria: the person involved in the crash was the driver of a large truck (e.g., single-unit truck with two or more axles, truck tractors, or other heavy trucks), holds a valid CDL license, and was found by the investigating officer to have contributed to the crash (and was not a mere victim). The dataset was partitioned based on gender, and each CHAID tree was developed using the contributing circumstances indicated previously as the predictor variables for the outcome of crash injury severity on three levels: fatal, injury, and property damage only. The built settings included an absolute value of a minimum of 10 records in the parent branch and a minimum of five records in the child branch as the stopping criteria; both the alpha for splitting and the alpha for merging were set at 0.05 and Pearson was the chi-square method employed. The dataset was partitioned into a training set (75%) and a testing set (25%) to test the classification accuracy of the model, and the final models resulted in an accuracy of 80.36% and 79.05% for male and female drivers, respectively.

The predictor importance, which indicates the relative importance of each circumstance for estimating the model, suggested by the CHAID model for crashes occurring in Missouri involving large truck CDL drivers is presented for male drivers in Figure 1 and female drivers in Figure 2.

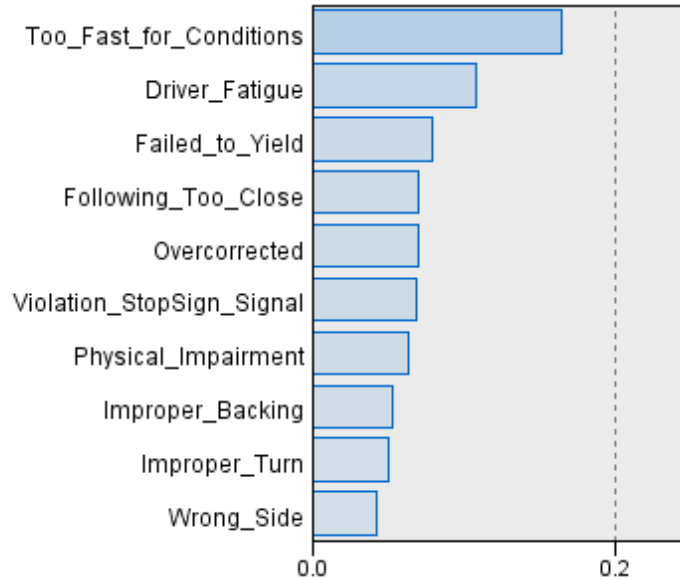


Figure 1. Predictor importance for crash severity for male CDL drivers

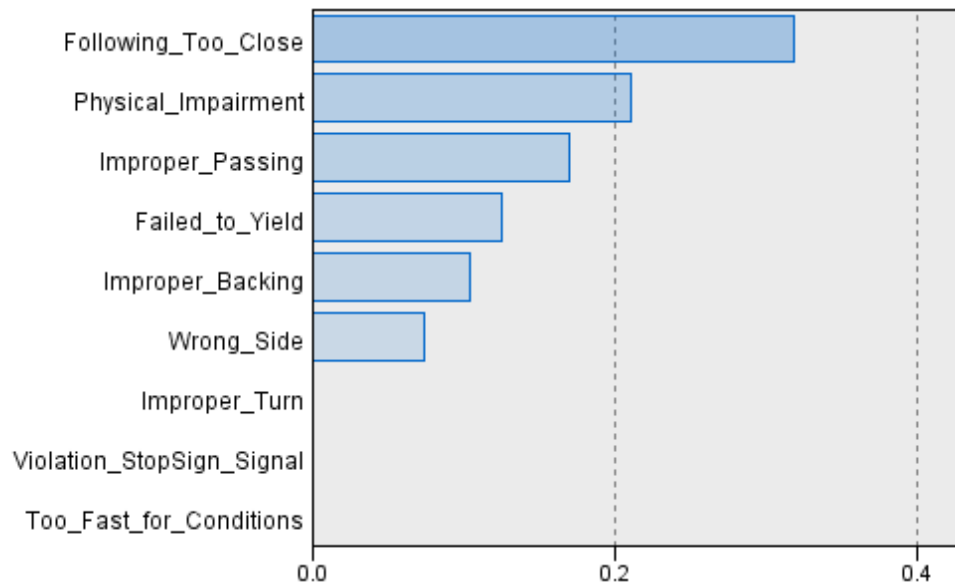
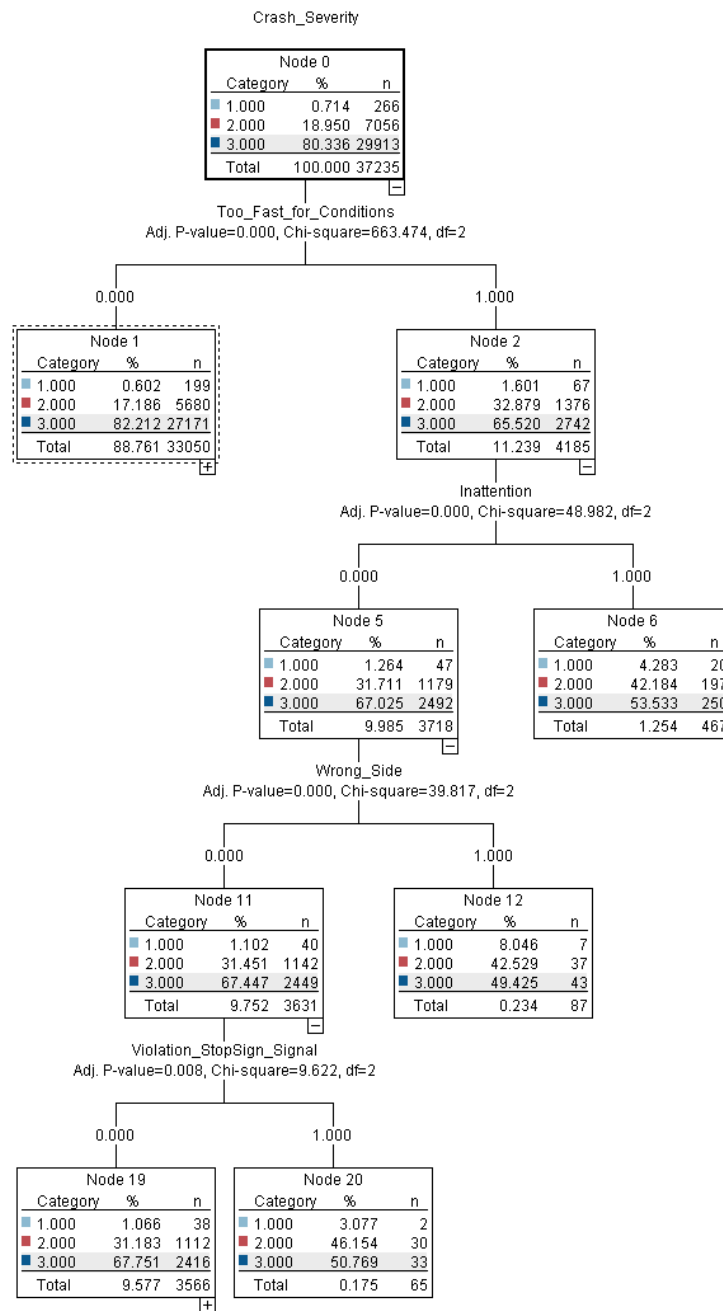


Figure 2. Predictor importance for crash severity for female CDL drivers

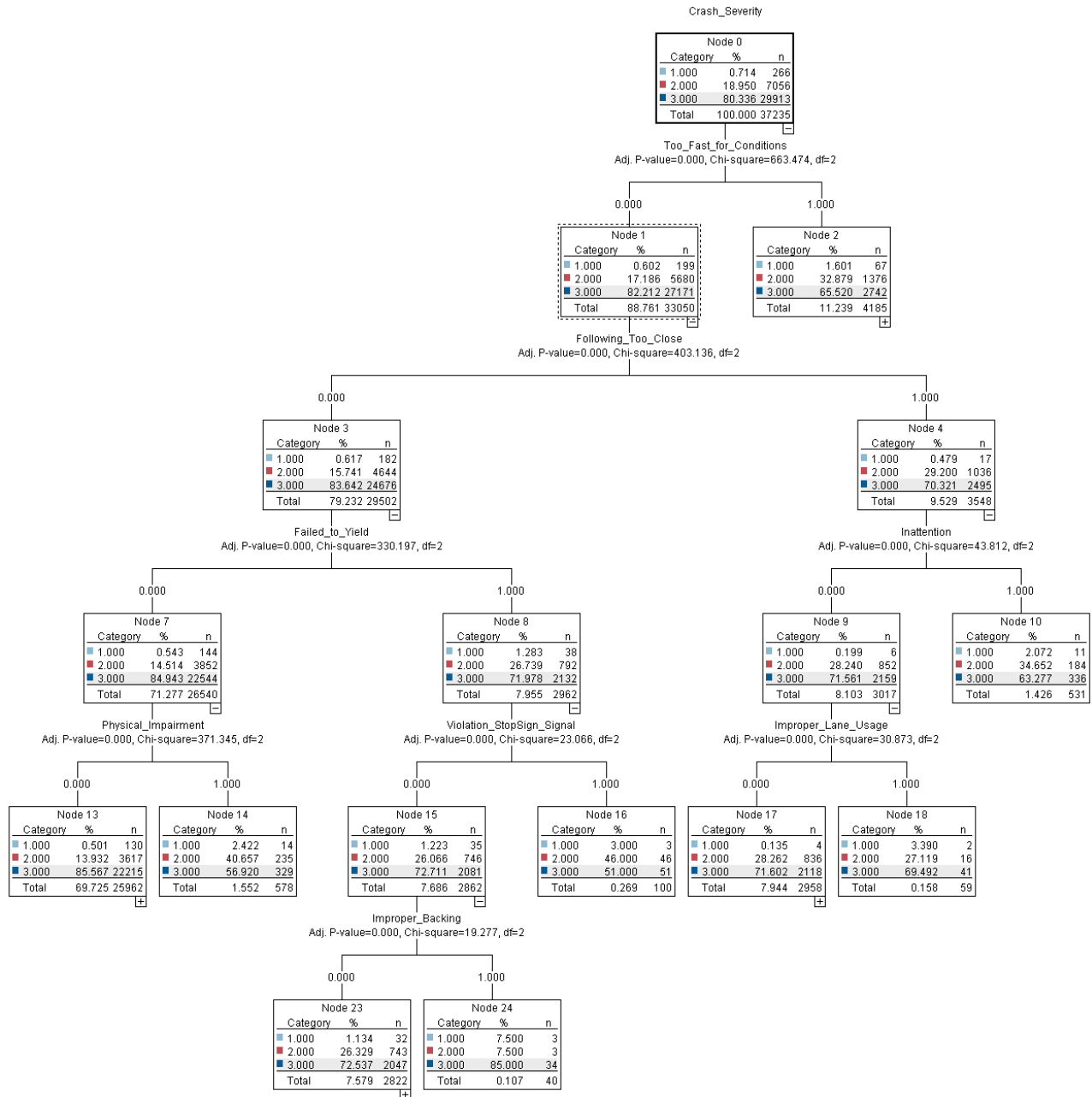
As illustrated in Figure 1, driving too fast for conditions, driver fatigue, failed to yield, and driving too close have the greatest significance for predicting crash severity for male drivers. For female drivers, as illustrated in Figure 2, following too close, physical impairment, improper passing and failing to yield have the greatest significance for predicting crash severity.

The CHAID decision tree model results for male drivers are presented in Figures 3 and 4 and illustrate the root node split for male CDL drivers as driving too fast for conditions.



Note: Only a portion of the decision tree is shown

Figure 3. CHAID Results for male CDL drivers when driving too fast for conditions is present



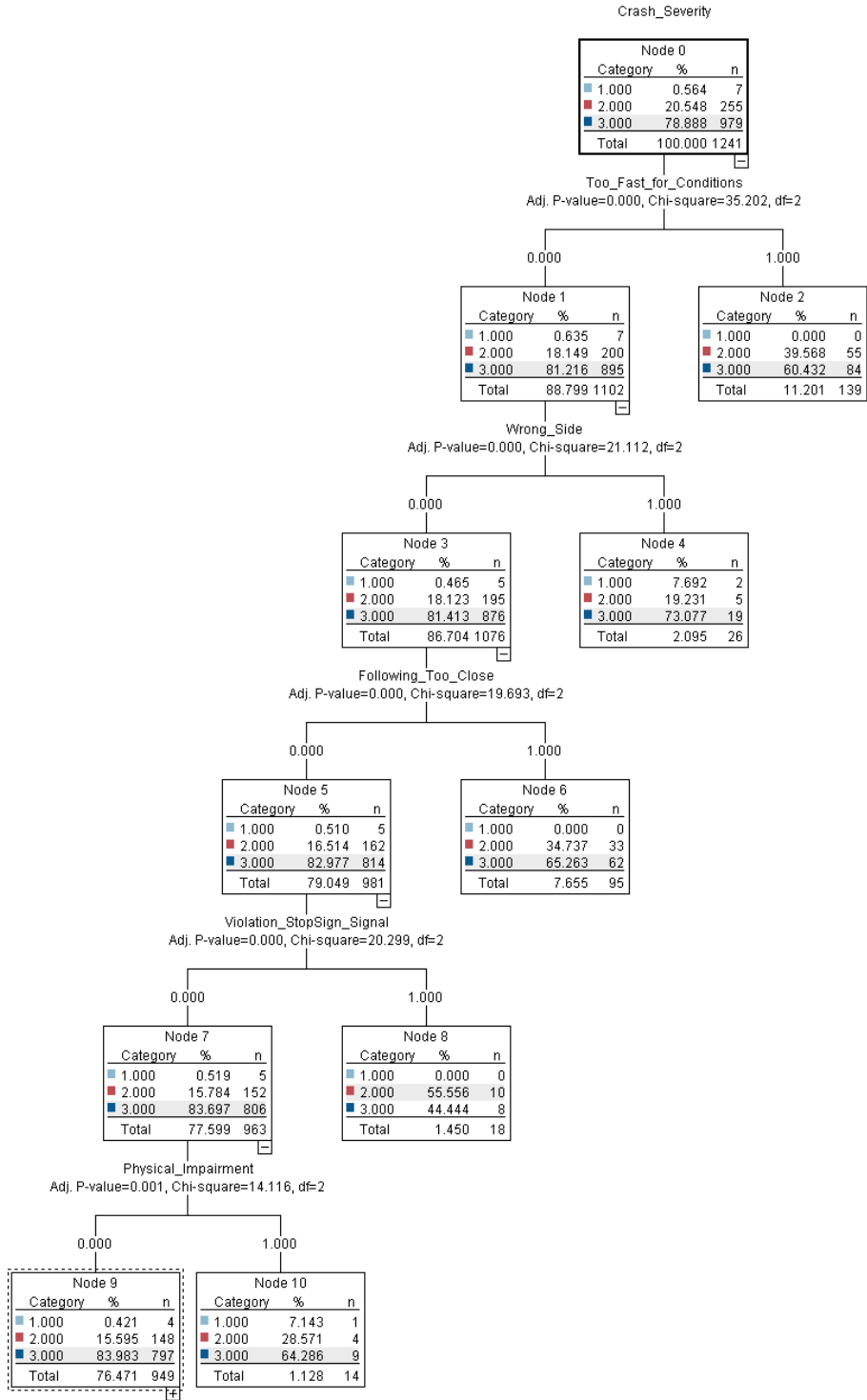
Note: Only a portion of the decision tree is shown

Figure 4. CHAID results for male CDL drivers when driving too fast for conditions is not present

When driving too fast for conditions is present, as illustrated in Figure 3, there is a 1.6% chance of a fatal outcome and a 32.9% chance of an injury outcome. When adding the presence of distraction/inattention to driving too fast for conditions, the chances of a fatal outcome and injury outcome increase to 4.3% and 42.2% respectively. Additionally, when the contributing factors are driving too fast for conditions while on the wrong side of the road (i.e., head-on collisions), the chance of a fatal outcome jumps to 8.0%.

When driving too fast is not a contributory crash factor, as illustrated in Figure 4, yet the driver is driving too close to another vehicle while not paying attention or is distracted, the probability of a fatal outcome equals 2.1% and probability of an injury outcome equals 42.2%. Worse so, when improper backing and failing to yield are exhibited together, the probability of a fatal crash occurring increases greatly to 7.5%.

When considering female CDL drivers, as illustrated in Figure 5, the root node split is driving too fast for conditions. When this circumstance is present, a 39.6% probability of an injury outcome exists. When driving too fast for conditions is not a contributory factor, yet driving on the wrong side of the road or physical impairment is a factor, the chance of a fatal outcome, given a crash occurs, is 7.7% and 7.1%, respectively. Interestingly, no interaction effects are found between factors for female drivers, which suggests that the behaviors' effects on the probability of crash severity are isolated.



Note: Only a portion of the decision tree is presented

Figure 5. CHAID results for female CDL drivers

CONCLUSIONS

Through the use of the CHAID methodology, this study was able to better understand the factors that affect crash injury severity as a function of truck drivers' gender in order to improve training programs and enhance driver safety.

The behaviors affecting crash severity differ with driver gender. Males' most significant predictors or modeling crash injury severity were found to be driving too fast for conditions and driver fatigue, which contrasts with females' top predictors of following too closely and physical impairment. This suggests that males are more likely to drive aggressively and drive while they are impaired by tiredness, while female truck drivers are more likely to be in a severe accident as a result of not being able to stop in time to avoid hitting the vehicle in front of them.

The decision trees for males and females also showed a profound difference in crash predictors. The decision tree for females had only one side, meaning that there are no interacting effects, and the crash severities were the result of one major factor. Conversely, the decision tree partitioned for male truck drivers had many more branches and interaction effects of different variables that contributed to overall crash severity. The most prominent of these interactions is when males are both driving too fast for conditions and are not paying attention while driving. When these two factors are both occurring simultaneously and a crash occurs, there is a 43% chance that an injury will result.

This information may be used to tailor truck driver training curricula to the students being taught. Females, for instance, could have more emphasis placed on proper following distances, whereas males might have more emphasis placed on following proper vehicle speeds, as well as fatigue preventing measures such as hours of service regulations. Such a customized approach has great potential to graduate safer truck drivers than previous driver curricula.

The results of this study and future studies from similar methodology may benefit the State of Missouri and the United States roadway transport system as a whole through a variety of actions that will increase the safety of large trucks that share the roads with passenger vehicles. Studies using effective big data analytics techniques may allow us to accomplish the following:

- Gain insight into predictors of injury severity, given a large truck crash occurs
- Uncover interaction effects between contributing circumstances and the impact on injury severity
- Contribute to driver education
- Contribute to the future of traffic safety

LIMITATIONS AND FUTURE RESEARCH

The major limitation of this analysis is the small sample size of female drivers. Future research should combine datasets to increase the sample size. Cooperative research between academia and driver training programs consisting of both quantitative (e.g., historical crash data) and qualitative (e.g., behavioral observations) will enhance driver education. Sub-partitioning the data based on gender differences, crash type, and location (e.g., highway versus city roadway) could better prepare students for specific condition interaction based on their genetic makeup. In this way, driving schools can tailor instruction based on the statistical crash predictors related to students' attributes (gender, age, etc.).

Additionally, crash severity and/or crash frequency analysis may be broadened to states surrounding Missouri to increase the sample size as well as increase driver safety endeavors. Since many truck drivers cross state borders on a regular basis, broadening the crash data analysis will allow for enriched policy recommendations grounded upon differing state laws and requirements. Additionally, assessment of the impact of differing topography and environmental conditions on crash severity/frequency of Missouri CDL drivers in bordering states will enhance Missouri CDL education.

Finally, this study only considers the contributing circumstance factors that affect crash severity. Additional analysis that considers environmental factors, such as weather, temperature, road conditions, etc., in addition to the contributing circumstances currently being explored, will better uncover factors that impact crash severity. This analysis can also surpass state borders to analyze if changing environmental conditions impact driver capabilities, and if policy, infrastructure, and/or equipment modification recommendations should be made.

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