Freeway crash and lane compliance under truck lane restriction and differential speed limit

Murat Korkut
Louisiana State University and Agricultural and Mechanical College

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FREEWAY CRASH AND LANE COMPLIANCE UNDER TRUCK LANE RESTRICTION AND DIFFERENTIAL SPEED LIMIT

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

in

The Department of Civil and Environmental Engineering

by

Murat Korkut
B.S., Louisiana State University, 2005
August 2009
Dedicated to my family...
ACKNOWLEDGEMENTS

I would like to take this opportunity to thank the people who have helped me live a better life. First, I would like to thank my parents, my sister, and my grandmother for their support throughout my life. They are the reason for my happiness! I am also grateful to Dr. Mehmet Tumay; I would not be where I am today without his kind help.

For his endless patience, optimism, and trust in me, I want to express my gratefulness to Dr. Sherif Ishak. For showing me the ropes to perfection and practicality at work…. special thanks to you, Dr. Brian Wolshon! For his guidance in the methodology of this thesis and for being on my advisory committee, I would like to thank Dr. Chester Wilmot.

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For giving me the opportunities to learn from the people whose names I mentioned and for helping me become a better person each and every day….I thank God!
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ABSTRACT

In the last decade, several fatal truck related crashes occurred on the elevated freeway over the Atchafalaya Basin. In an attempt to reduce the crash rates, the Louisiana Department of Transportation and Development implemented two policies to regulate the truck traffic on this rural divided freeway that has two lanes in each direction of flow. These policies restricted truck traffic to the right lane and reduced the maximum truck speed limit to 55-mph. On the other hand, maximum car speed limit was kept at 60-mph. The changes took place in 2003. While the policies were in effect, crash and traffic data were collected over the freeway. This study investigated the relationship between crash rates and traffic characteristics such as lane distribution of truck traffic, truck and car percentages exceeding the speed limits, difference between truck and car speeds, speed variance, truck volume, and lane occupancy. Multiple linear regression of total and truck-involved crash rates on the traffic characteristics showed that violation of the lane restriction and truck speed limit, truck speed variance, difference between car and truck hourly mean speeds, and lane occupancy were positively correlated with the crash rates.
1. INTRODUCTION

1.1 Background

In the last decade, several fatal truck related crashes occurred on the elevated freeway section over the Atchafalaya Basin. In an attempt to reduce the crash rates, new policies were implemented on the bridge. The policies restricted truck traffic to the right lane and reduced the maximum truck speed limit to 55 mph. No change was made on policies regulating car traffic. Car speed limit was kept at 60 mph and cars continued to travel in both left and right lanes.

The Louisiana Department of Transportation and Development (LA DOTD) sponsored a research study to assess the aforementioned strategy’s impact on total and truck-involved crash rates. The comparison of crash rate from three years before and three years after the implementation of the policies revealed 79 percent reduction in the truck-involved crash rate, and 13 percent reduction in the total crash rate.

This thesis further investigates the relationship between traffic characteristics and crash characteristics on the bridge while truck lane restriction and differential speed limit policies were in effect.

1.2 Motivation

Transportation researchers such as Garber et al. (2006), Gan and Jo (2003) studied the impact of truck lane restriction and differential speed limit solely on crash rate or on traffic behavior. However, seeking a relationship between crash rate and the
traffic characteristics in the presence of truck lane restriction and differential speed limit is not common in literature. Such an approach might help enhance the knowledge about the safety impact of lane restriction and differential speed limit on four-lane rural elevated freeways.

A before-after crash analysis conducted by Ishak et. al. (2008) found reduction in the crash rates on the Atchafalaya Basin Bridge after the implementation of truck lane restriction and differential speed limit on the bridge. However, traffic behavior was not taken into consideration in the crash analysis. Analyzing the crashes based on variables such as left lane truck percentage, speed limit violation rate, speed variance, lane occupancy, and truck percentage in the stream would help better assess the policies’ impact on traffic safety. More specifically, it might help determine whether the reduction in crash rates can be associated with the policies in force. Further, this analysis might help indicate the factors that have the potential to increase or decrease crash rates significantly. Identifying such factors might help set countermeasures to improve the traffic safety on the bridge.

1.3 Problem Statement

Louisiana Department of Transportation and Development attempted to improve traffic safety over the Atchafalaya Basin Bridge by restricting truck traffic to the right lane and reducing the truck speed limit from 60 to 55 mph. A before-after crash analysis showed reduction in crash rate after the change in regulations. However, behavior of trucks and cars under the new policies in force were not taken into account in the crash analysis. Compliance with the policies might not always be 100 percent. In order to
measure the policies’ effectiveness in reducing the crash rates, trucks’ lane use behavior and speeds should be related to crash rates. In fact, car speeds should be taken into consideration too, because a high car speed variance or high difference between car and truck mean speeds might increase the likelihood of crashes even if trucks are obeying the laws.

Further, the impact of truck volume or truck percentage on crash rates is not known. High truck volume might slow the traffic but at the same time increases the probability of a truck-involved crash. On the other hand, high truck percentage in the traffic stream might help reduce crash rates due to more uniform flow. Further knowledge of interest that has not been explored was the relationship between lane occupancy and the crash rate. As the lane occupancy increases, drivers may prefer making fewer lane changing maneuvers and pay more attention to the road. This may impact the likelihood of crashes.
2. OBJECTIVES

The main goal of this research is to help find out if traffic safety on the Atchafalaya Basin Bridge was impacted by restricting truck traffic to the right lane and setting the truck speed limit and car speed limit to 55 mph and 60 mph, respectively, and if so, the extent to which it is the case.

To accomplish the goal, the objectives of this research will be:

1. To review the previous studies on truck lane restriction and differential speed limit to learn about the impact of such policies on crash rate, speed, and volume on rural freeways, with emphasis on elevated rural freeways.

2. To determine the traffic characteristics that may be correlated with the total and truck-involved crash rates.

3. To conduct multiple linear regression analysis to determine the factors that were significantly related to the total and truck-involved crash rates.
3. LITERATURE REVIEW

Restricting trucks to certain lane(s) of a freeway or setting different speed limits for trucks and cars have been some of the approaches taken by transportation authorities to improve highway safety or traffic flow since 1980s. Some authorities such as Virginia DOT have tried both applications simultaneously while some authorities such as Florida DOT have implemented variations of these policies such as lane restrictions based on time of day (Harwood et. al.).

Studies have been conducted by transportation researchers to evaluate the effectiveness of truck lane restriction and differential speed limit strategies. Impact of such regulatory practices on variables such as crash rate, lane distribution, average speed, density, frequency of lane changing maneuvers has been explored using statistical techniques such as Empirical Bayes’ Technique or by creating simulation models. (see for instance, Garber, 2003; Gan and Jo, 2003)

One of these studies was conducted by Stokes and McCasland in 1986. This study evaluated the applicability as well as potential safety and operational influences of truck restrictions and regulatory practices in Houston, San Antonio, and Dallas. Lane restrictions and speed restrictions were among the examined restrictions and regulatory practices.

Due to the frequent freeway to freeway interchanges and lane drops on freeways in the Houston, San Antonio, and Dallas areas, trucks were most likely to drive in the center lane(s). If trucks were to be restricted to the far right or far left lanes, the establishment of transition areas before and after lane drops would be required.
Transition areas would also be required if trucks were to be restricted from driving in the far right or left lanes except to exit and enter the freeway. These transition areas would allow time for trucks to shift to other lanes in the vicinity of lane drops. However, in both scenarios, the large number of lane changing maneuvers by heavy trucks (i.e. more than three axles) in a short distance would trigger the occurrence of crashes and reduce the traffic flow. Another handicap was the difficulty of defining the limits of the transition area. Besides, if trucks were to be restricted to the right lane it would be difficult for other drivers to see the overhead signs that were located above the right lane.

On the other hand, the speed data demonstrated that the frequency of truck related accidents were high when the average speed for all vehicles was high. Therefore, a reduced uniform speed limit would reduce truck related accidents. Stokes and McCasland pointed out that after the speed limit was reduced from 70 mph to 55 mph in 1974, the proportion of accidents in which trucks hit the rear end of cars increased although the number of total accidents decreased. This fact implied that the average truck speed did not decrease as much as car speeds did. On this basis, the authors concluded that the conflicts between cars and trucks could be reduced by either better enforcement or differential speed limit application.

Zavoina et al. (1991) tested prohibiting trucks from driving in the left lane on a six lane rural interstate near Fort Worth, Texas. Truck and car speed limits at this location were 60 mph, and 65 mph, respectively. The nine mile long test section was on a three percent upgrade eastbound and a three percent downgrade westbound. Its average annual daily traffic was 39,000 vehicles. Peak periods in the westbound and eastbound
directions were determined to be 4 P.M. – 6 P.M., and 6.30 P.M. – 8.30 P.M., respectively.

After the lane restriction implementation, the percentage of trucks in the left lane decreased by approximately 63 percent of the directional total truck traffic. This percentage was different only at nonpeak time in the westbound direction when it climbed up to 76 percent.

Increase in the right lane truck volume after the lane restriction implementation was significant. This increase was equal to 19.8 percent of the directional total truck traffic at peak time in eastbound direction. The increase at nonpeak time in westbound direction was 13.6 percent of the directional total truck traffic. The car distribution did not demonstrate any practically significant change. The maximum percentage change was 2.5 percent.

Due to the site being a rural freeway and also due to the low volume to capacity ratio, the truck volume increase in the center and right lanes did not affect the time gap between trucks and cars. This value was approximately five seconds even at peak times.

Truck speeds did change, but this change did not show any trend or could not be attributed to the restriction. The authors concluded that the results obtained could not be generalized for all highways. Similar results for other sites could only be obtained if the chosen site was a rural highway with low total and truck volume. Zavoina et.al. pointed out the need for further research to find how to adapt the obtained results to roadways with large total and truck volumes.
Koehne et al. (1996) tested restricting trucks to rightmost two lanes on I-5 in the state of Washington. The test site had five lanes in one direction, at which the far left lane was an HOV lane. The vertical grade at this location was four percent. The lane restrictions were one directional; only on the uphill grade. Speed limit was 55 mph.

Results of a before-after traffic data comparison indicated that truck volume in the restricted lane did not change after the restriction implementation. It remained at five percent during the weekdays and at two percent on the weekends. This outcome suggested that trucks either willfully violated the restriction or were not aware of a lane restriction. The violation rate increased significantly when the congestion was high at afternoon peak, which was determined to be between 2 P.M. – 8 P.M.

Lane restriction implementation caused platoon lengths in the rightmost two lanes to increase. The study found out that even at 100 percent compliance with the restriction, the pavement life would be affected minimally, because the volume of trucks that traveled in the prohibited lane was low before the restriction implementation. The reason for the majority of truck-involved crashes was changing lanes to the right. This finding indicated that restricting trucks from the left lane might increase truck-involved crashes.

Further, the authors calculated the annual loss to the trucking industry if a lane restriction was implemented. Taking into consideration the total number of trucks that crossed the test sections, average frequency of travel over the sections, average truck speed in the prohibited lane, average truck speed in the lane adjacent to the prohibited
lane, length of the test sections, and the annual salary of a truck driver, the annual loss for the trucking industry as a whole was calculated to be $1,155.

Results of an opinion survey indicated that 91 percent of non-truck drivers were in favor of truck lane restriction while only 32 percent of truck drivers supported the implementation of permanent lane restriction. Based on the overall results, further implementation of truck lane restriction in Puget Sound Region was not recommended. Though, authors recommended further research to explore why the majority of non-truck drivers were in favor of the restriction.

Cate et al. (2004) evaluated the traffic safety impact of lane use restrictions implemented on Tennessee’s highways. Tests showed that even with minimal use of signage and enforcement, the truck percentage in the left lane decreased significantly after the lane restriction was implemented. The study recommended the implementation of truck lane use restrictions on freeways with at least three lanes in one direction. However, restricting trucks to a single lane was not recommended, because the barrier effect and the accelerated pavement wear would prevail over the potential benefits of the restriction.

Using pavement markings to indicate the truck lane restrictions, placing warning signs on the center median, overhead structures or on the right shoulder to remind the drivers of the restriction and to take the attention of noncompliant drivers one mile before the restriction area were considered essential in the success of the lane restriction policy. Another recommendation was that truck lane restrictions be
temporarily lifted if a work zone was located at the site of the restriction, due to the safety concerns.

Field data from the site of the lane restriction indicated increase in the truck speed in few observations. But in general, truck speed decreased after the lane restriction implementation. Overall, lane use restrictions provided few tangible operational and safety benefits, and produced the insight of enhanced safety and comfort in the majority of the motorists. After meeting all other requirements, the public insight would help the widespread practice of the truck lane restrictions in Tennessee, according to the authors of this study.

A study by Agent and Pigman (2002) investigated the impact of large trucks on highway safety. The report summarized a set of countermeasures to address truck crashes on interstate highways after analyzing crash data, discussing with truck industry representatives, and reviewing the state-of-the-art procedures and technologies that might help improve traffic safety. The authors suggested that truck lane restriction should be used on sections with at least three lanes in one direction. Also they suggested implementation of ITS solutions (i.e. real-time traffic congestion/information system, automated screening of trucks to reduce congestion at weigh stations, speed monitoring equipment and truck speed advisory systems to warn drivers about low design speeds, etc).

A report, by Garber et al. (2003), evaluated the safety effects of differential and uniform speed limits on rural interstate highways. Results of a before-after study for five states showed that changing from a uniform speed limit to a differential speed limit or
vice versa had no impact on the mean speed or speed variance. Also, crash rates had no association with the type of speed limit chosen.

Hanscom (1990) compared the traffic behavior at two different sites where lane restriction was in force. One of the sites had three lanes in one direction, but trucks were not allowed to travel in the far left lane. The other site was a rural interstate and had two lanes in one direction. Trucks were not permitted to drive in the right lane of this freeway due to high pavement deterioration. The first restriction reduced the congestion at the site. However, the second scenario resulted in high violation rate by trucks slower speeds.

Mussa and Price (2004) evaluated the traffic safety impact of a truck lane restriction on I-75 in Florida. Trucks were not permitted to travel in the leftmost lane on this freeway. The freeway had three lanes in each direction and was on a rolling terrain. It was relatively uncongested (service level B). Simulation analysis showed that lane restriction did not cause significant difference in travel times for all vehicles; however it reduced the frequency of lane changing maneuvers. The frequency of lane changing maneuvers was lower at night time (7 P.M.-7 A.M.) compared to daytime (7 A.M.-7 P.M.). Crash analysis revealed that 48 percent of the crashes involving trucks only and 28 percent of all crashes occurred due to improper lane changing. This was the most frequently cited cause of crashes. Authors concluded that rescinding the lane restriction policy would have negative impacts on crash rate, since the frequency of lane changing maneuvers were likely to increase.
In his article, Zeitz (2003) discussed South Carolina’s strategy to reduce traffic accidents. South Carolina Department of Transportation (SCDOT) implemented truck lane restrictions temporarily for one year at sites that constituted high risk for crashes. Targeted enforcement was applied both for lane violations and aggressive driving violations. In the outcome, the truck related accident rates decreased by 78 percent. This result facilitated FHWA, SCDOT, the South Carolina Department of Public Safety, and the South Carolina Truckers Association to reach a consensus that restricting trucks from the leftmost lane on three-lane sections would improve traffic safety and operations.

Borchardt (2002) discussed the implementation and results of restricting trucks to the middle and right lanes on a freeway that had three lanes in each direction. Compliance rate with the restriction was 95 percent, and the crash rate reduced by 68 percent at the end of a 36-week evaluation period. The restriction did not cause a significant change in travel time. Further, 90 percent of the surveyed automobile drivers supported the permanent implementation of truck lane restriction policy.

Hoel and Peek (1999) investigated the impacts of lane restriction on traffic flow elements such as density, lane changing, and speed variance. Three test sites were chosen on I-81 in Virginia. The FRESIM simulation model was used to approximate traffic flow elements. Two different restriction strategies were tested: restricting trucks from the left lane and restricting trucks from the right lane. The results indicated a decline in density and frequency of lane changes, and an increase in speed differentials when trucks were restricted from using the left lane at four percent upgrade.
On the other hand, there was an increase in the frequency of lane changing maneuvers when trucks were restricted from using the right lane. Another important finding was that the impact of truck lane restriction were dependent on the site characteristics. Based on these findings, Hoel and Peek recommended restricting trucks from using the left lane on grades four percent or steeper. They also suggested that trucks should not be restricted from the right lane.

Gan and Jo (2003) tested the impact of truck lane restriction on average speed, throughput, speed differentials, and frequency of lane changes. They tested 12 different scenarios in which trucks were not permitted to travel in the leftmost lane(s). The test sites had three to six lanes in one direction. Simulation results showed that average speed increased as interchange density, truck volume, and ramp volume decreased. On the other hand, there was considerably high speed differential between restricted and non-restricted lane groups, and the magnitude increased proportionally with the increase in the number of interchanges, ramp volumes, truck percentages, and free-flow speed.

Authors also found out that lane restrictions separated the slower vehicles from the faster ones and reduced the frequency of lane changing maneuvers. Highest throughput, lowest speed differential between restricted and non-restricted lane groups, and lowest frequency of lane changing maneuvers were obtained when trucks were not permitted to travel in the leftmost lane on freeways with three to five lanes in one direction. Similar results were obtained when trucks were not permitted to travel in the leftmost two lanes on four and five lane highways with low interchange density and truck percentage of 15 percent or less.
A simulation study by Cate and Urbanik (2003) showed the effect of restricting trucks from the left lane on 3-lane highways. The VISSIM traffic simulation model was used to test different scenarios and analyze the results. Truck lane restriction caused a slight increase in the vehicle density and level of service on flat grades. However, as uphill grades approached four percent, the impact became more significant. Similarly, the average travel time was affected slightly on flat grades, although it reduced considerably on steep (four percent) uphills.

The study also showed that speed differential between cars and trucks was less than 1 mph on flat sections, while this value climbed up to 9.9 mph on steeper sections of the highway. Another variable tested was the frequency of lane changing. The reduction in the frequency of lane changing maneuvers by trucks surpassed that by cars on flat sections, but they were almost same on uphill sections. The safety problem generated from the speed differential between cars and trucks was offset by the safety benefits of low frequency of lane changing. Overall, prohibiting trucks from using the leftmost lane on highways with three or more lanes in the same direction had no negative effect on highway safety or operating efficiency.

Kuhn et al. (2002) studied the current state of the practice in managing lanes. The report discussed the results of a survey that investigated the experiences of the states in lane restrictions. This investigation was done upon the request of Federal Highway Administration in 1986. Survey results showed that lane restrictions were being used in 26 states. While 14 states implemented the restrictions to improve highway operations, 8 sought reduction in accidents, 7 considered benefits in pavement
structures, and 7 required restrictions in construction zones. The number of states that reported combinations of reasons was 20.

Douglas et al (2003) compiled the current strategies in practice to manage the truck traffic on U.S. highways. Their report pointed out the rapid increase in the truck volume on roads compared to the increase in population, overall vehicle travel, and highway capacity. Further, Douglas et al. surveyed 28 state departments of transportation and 8 metropolitan planning organizations that started projects and implemented strategies to manage the increasing truck traffic and the challenges truck traffic created. Lane restriction was one of the most frequent strategies selected by respondents. The other common strategies suggested by the respondents were improved pavement, climbing lanes, and weigh-in-motion.

According to the respondents, safety was the primary and congestion was the secondary concern for adopting lane restrictions for trucks. Time-of-day restrictions were primarily implemented to reduce congestion, secondarily to reduce safety. Although lane restriction was a popular strategy nationwide, two states considered but then rejected implementing lane restriction policies due to the insufficient benefits and difficulty of implementation. The same was true for the time-of-day restrictions though it was not as commonly practiced as lane restriction.

Fontaine (2003) discussed the findings of a study on the engineering and technology solutions to enhance large truck safety in Virginia. The Virginia Department of Transportation (VDOT) employees were surveyed to find out the engineering and technology actions that were being taken in Virginia. Survey respondents mentioned the
effectiveness of truck lane restrictions on truck climbing lanes or steep uphill three-lane directional sections. They also pointed out the improvement in the traffic flow and safety on U.S. 29 through the Madison Heights area of Amherst County as a result of restricting trucks to the right lane.

On the contrary to the positive opinions of the survey interviewees and the results of many other studies conducted around the nation on the benefits of truck lane restrictions, and the data from the study of lane restrictions on the Beltway and I-95 showed that lane restriction contributed to the increase in the crash rates. Fontaine stated that the benefits of truck lane restriction strategy were still not evident due to the limited data on this subject. Likewise, it was not known whether differential or uniform speed limit between cars and trucks were safer. The report underlined the necessity of further research in these two areas.

Harwood et al. (2003), in their work, entitled “Highway/Heavy Vehicle Interaction: A Synthesis of Safety Practice”, stated that the fraction of the highway agencies that used or were considering the use of differential speed limits was 2/5; however, the safety benefits of differential speed limits was stated to be not proven. In fact, the speed variance between the passenger vehicles and heavy vehicles might cause more traffic accidents. Harwood et al. recommended conducting more research on differential speed limits and truck lane restrictions in order to explore their impacts on highway safety.

According to Knipling et al. (2004), truck lane use restriction is appropriate for interstates with at least three lanes in one direction. Pilot studies were recommended to
ensure the safety benefits of potential lane restrictions. As stated in the report lane use restrictions required the authorization of the legislation, but the legislation sometimes authorized state DOT’s and local agencies to apply the lane use restrictions on facilities under their control. All the stakeholders, primarily law enforcement officials and organizations that represent the commercial transporters using heavy trucks, should be informed in the implementation stage of the lane use restriction. Further, the authors suggest conducting a survey to obtain truckers’ perceptions about the lane restriction strategy.

3.1 Summary

In summary, more studies reported safety improvement due to truck lane restriction than those that reported the opposite (nine studies reported safety improvement as opposed to seven studies that reported reduction in safety). On the other hand, three studies found no impact. The result was mainly dependent on the number of lanes and the vertical alignment at the site, configuration of lane restriction, percent truck volume at the test section, and time of day the restriction was in effect.

Three studies compared the safety effects at sites with different number of lanes. All of them reported safety improvement on highways with at least three lanes in one direction.

12 studies investigated the safety effects of lane restriction at different configurations. Three tested lane restrictions on uphill sections and all three found reduction in crash rate. Further, seven studies evaluated restricting trucks from the left
One study showed that restricting trucks to one lane on three, four and five lane highways resulted in crash rate reduction. In contrast, another study found that single lane restrictions were detrimental to pavement life and in fact caused crash rates to increase. On the other hand, three studies that compared the impact of differential speed limit and uniform speed limit found no impact of differential speed limit on traffic safety.
4. DATA COLLECTION

4.1 Introduction

Crash and traffic data collection was performed on the Atchafalaya Basin Bridge to obtain information on the volume, speed, lane occupancy, and the number of crashes that happened over the bridge when the lane restriction and differential speed limit policies were in force. The next sections describe the study section, the traffic data collection process, and the crash data characteristics.

4.2 Study Section

The traffic and crash data collection were conducted over an 18.2 mile elevated section of I-10 in Louisiana, as shown in the Figure 1. The freeway spans the Atchafalaya Basin Swamp in east and west directions between mileposts 117 and 135.2. The section is divided by a median, as shown in Figure 2, and has two lanes and two shoulders in each direction. Each lane is 12 ft. wide. The right and left shoulders are 12 ft. wide and 6 ft. wide, respectively, except in some areas where the shoulder width decreases to 4 ft. on both right and left sides. Figure 3 shows a snapshot of a narrow shoulder warning sign.

Along the segment, trucks are not allowed to travel in the left lane. Signs inform the truck drivers about the lane restriction policy, as shown in Figure 4. Further, the truck speed limit along this section is 55-mph while the car speed limit is 60-mph. A variable message sign at the westbound end of the bridge warns the drivers about the 55-mph reduced truck speed limit on the bridge, as shown in Figure 5. Each direction of
flow contains raised reflective markers and rumble strips for improving traffic safety. These were placed on the bridge in August, 2003.

Figure 1. Map of the Study Section

Figure 2. View of the Bridge and Differential Speed Limit Signs
Figure 3. Narrow Shoulder Warning Sign

Figure 4. Truck Lane Restriction Warning Sign
4.3 Traffic Data Collection Process

The traffic data were collected between June 11, 2007 and September 26, 2007. Lane-by-lane volume, average speed, and occupancy for 30-second time intervals were collected by four RTMS (Remote Traffic Microwave Sensor) devices.

Table 1 shows the locations of these devices. A screenshot of a sample traffic data is shown in Table 2. As seen in the table, the information that was provided in every 30 second record included the RTMS device identification number, the lane in which the data were collected, the date and time of the data collection, volume, average speed of all vehicles during that 30 second interval, and occupancy.
Table 1. RTMS Locations

<table>
<thead>
<tr>
<th>Identification Number</th>
<th>Milepost</th>
<th>Direction</th>
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</thead>
<tbody>
<tr>
<td>20</td>
<td>126.4</td>
<td>Westbound</td>
</tr>
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<td>21</td>
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<td>Eastbound</td>
</tr>
<tr>
<td>23</td>
<td>122.1</td>
<td>Eastbound</td>
</tr>
</tbody>
</table>

There were four fields that provided volume information. First field “Volume” reported the total 30-second volume. The field “Vol_Mid” reported the volume of vehicles that were 26 to 36 feet in length, the field “Vol_Long” reported the volume of vehicles that were 36 to 56 feet in length, and the field “Vol_Extra_Long” reported the volume of vehicles that were 56 to 76 feet in length. Truck volume was calculated by adding the volumes reported for “Vol_Long” and “Vol_Extra_Long” fields. Subtracting the truck volume from the total volume yielded the car volume. The field “Occupancy” reported the lane occupancy.

Schematic representation of the data collection process is illustrated in Figure 6. First, the RTMS devices detected volume and speed of the vehicles in the right and left lanes of each flow direction during a 30-second time interval, and transmitted this information wirelessly to an LA DOTD tower. This tower was located next to Butte La Rose interchange at milepost 120 in the eastbound direction of the bridge. The signals were received by the tower antenna and transmitted by a cable to the radio that was located in the tower control room. A cluster controller that was connected to the radio by a cable received the data packets and stored the information. A cellular modem was connected to both the radio and the cluster controller by cable. The data that were stored in the cluster controller were sent to an office computer at Louisiana State
University wirelessly via the cellular modem. WATER software requested the data from the cluster controller via a TCP/IP protocol and stored the polled data into a Microsoft SQL Server, which was the final destination of the data.

Due to uncontrollable factors such as RTMS or cellular modem malfunctioning, there were interruptions in the traffic data collection process. Therefore, data for some time periods were not recorded. These time periods added up to 30 percent of the 108 day data recording period.

Table 2. Screenshot of the Traffic Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>RTMS_ID</th>
<th>Zone</th>
<th>Speed</th>
<th>Volume</th>
<th>Vol_Mid</th>
<th>Vol_Long</th>
<th>Vol_EXTRA_LONG</th>
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4.4 Crash Data

The crash database, on the other hand, included information on 465 crashes that happened between years 2004 and 2006. 103 crashes involved trucks. The fields of the database that were useful to this study were type of vehicle involved, hour, day of the week, and direction. These are illustrated in Table 3. The definition of the field codes for fields “TYPE_VEH1”, “TYPE_VEH2”, “DIRECTION1”, and “DIRECTION2” are presented in Table 4. Number “1” for the field “WEEKDAY” stands for weekdays. The numbers between “01” and “24” in the field “HOUR” represent the hours of a day between “1 A.M.” and “12 A.M.”, respectively.
### Table 3. Screenshot of the Crash Data

<table>
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<tr>
<th>ACC_DATE</th>
<th>WEEKDAY</th>
<th>HOUR</th>
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<th>TYPE_VEH2</th>
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<th>DIRECTION2</th>
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<tr>
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### Table 4. Crash Database Field Codes

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<th>TYPE_VEH1/TYPETYPE_VEH2</th>
<th>Definition</th>
<th>DIRECTION1/DIRECTION2</th>
<th>Definition</th>
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<td>A</td>
<td>Passenger car</td>
<td>E</td>
<td>eastbound</td>
</tr>
<tr>
<td>B</td>
<td>Pickup truck</td>
<td>W</td>
<td>westbound</td>
</tr>
<tr>
<td>C</td>
<td>Van</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Single unit truck w/2 axles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Single unit truck w/3 axles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Truck trailer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Truck tractor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>Tractor semi trailer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>SUV</td>
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5. METHODOLOGY

5.1 Introduction

The methodology used in this study is based on determining a linear relationship between hourly crash rates and hourly traffic characteristics in the presence of truck lane restriction and differential speed limit. The traffic characteristics included compliance with lane restriction and speed limit, compliance, speed variance, truck exposure, and lane occupancy.

Since the traffic data and crash data were not collected concurrently, an assumption was made to model a relationship between crash rates and traffic characteristics. It was assumed that observed traffic conditions during data collection period were representative of the prevailing traffic conditions at the crash time and location. To explain this assumption more clearly, lane occupancy is used as an example. The occupancy values recorded between 1 P.M. and 2 P.M. during the entire traffic data collection period were averaged over the period of traffic data collection, which was 108 days. The resultant value was assumed to be equal to the average occupancy value in the 1 P.M. – 2 P.M. time interval during the crash data collection period.

The first step of the data analysis was to obtain the hourly values for total and truck-involved crash rate. The second step involved obtaining the hourly values for traffic characteristics lane compliance, speed limit compliance, speed variance, difference between hourly car and truck mean speeds, truck and total exposure, and
lane occupancy. The third step involved multiple linear regression of crash rates on traffic characteristics. The next sections describe these steps.

### 5.2 Crash and Traffic Characteristics

Table 5 shows the formulas for the dependent and the independent variables used in the multiple regression analysis.

<table>
<thead>
<tr>
<th>DEPENDENT VARIABLE</th>
<th>Crash Rate</th>
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<td><strong>Table 5. Variables Used in the Analysis</strong></td>
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<tr>
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<tr>
<td>$cr$</td>
<td>$\frac{n \times 10^8}{365 \times 18.2 \times q_{total}}$</td>
</tr>
<tr>
<td>$q_{total}$</td>
<td>$\frac{q_{total,agg} \times 120}{m}$</td>
</tr>
<tr>
<td>$cr$ :</td>
<td>hourly number of crashes per 100 million vehicle-miles</td>
</tr>
<tr>
<td>$n$ :</td>
<td>hourly number of crashes recorded over three years of data collection</td>
</tr>
<tr>
<td>$q_{total}$ :</td>
<td>hourly total volume</td>
</tr>
<tr>
<td>$q_{total,agg}$ :</td>
<td>hourly total volume recorded over 108 days</td>
</tr>
<tr>
<td>$m$ :</td>
<td>hourly number of observations</td>
</tr>
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</table>

(Table Cont’d)
<table>
<thead>
<tr>
<th>INDEPENDENT VARIABLES</th>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
</table>
| Percentage of Trucks in the Left Lane | $P_{t, left} = \frac{q_{t, left}}{q_{total}} \times 100$ (3) | $P_{t, left}$: percentage of trucks in the left lane  
$q_{t, left}$: hourly volume of trucks in the left lane  
$q_{total}$: hourly total volume |
| Difference between Car and Truck Hourly Mean Speeds | $\Delta_v = \bar{v}_c - \bar{v}_t$ (4) | $\Delta_v$: speed difference  
$\bar{v}_c$: hourly mean speed of cars  
$\bar{v}_t$: hourly mean speed of trucks |
| Percentage of Trucks Exceeding 55-mph | $P_{v_t>55} = \frac{q_{v_t>55}}{q_{total}} \times 100$ (5) | $P_{v_t>55}$: percentage of trucks exceeding the speed limit  
$q_{v_t>55}$: hourly volume of trucks exceeding the speed limit  
$q_{total}$: hourly total volume |

(Table Cont’d)
<table>
<thead>
<tr>
<th>Percentage of Cars Exceeding 60-mph</th>
<th>$P_{v_c&gt;60} = \frac{q_{v_{c&gt;60}}}{q_{total}} \times 100$ (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{v_c&gt;60}$ : percentage of cars exceeding the speed limit</td>
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</tr>
<tr>
<td>$q_{v_{c&gt;60}}$ : hourly number of cars exceeding the speed limit</td>
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</tr>
<tr>
<td>$q_{total}$ : hourly total volume</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Car Speed Variance</th>
<th>$\sigma_{v_{c}} = \frac{1}{11} \times \sum_{i=1}^{12} (v_{c_i} - \bar{v}_{c})^2$ (7)</th>
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<tbody>
<tr>
<td>$\sigma_{v_{c}}$ : hourly car speed variance</td>
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</tr>
<tr>
<td>$v_{c_i}$ : car speed in a five minute period</td>
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<tr>
<td>$\bar{v}_{c}$ : hourly mean car speed</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Truck Speed Variance</th>
<th>$\sigma_{v_{t}} = \frac{1}{11} \times \sum_{i=1}^{12} (v_{t_i} - \bar{v}_{t})^2$ (8)</th>
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</thead>
<tbody>
<tr>
<td>$\sigma_{v_{t}}$ : hourly truck speed variance</td>
<td></td>
</tr>
<tr>
<td>$v_{t_i}$ : truck speed in a five minute period</td>
<td></td>
</tr>
<tr>
<td>$\bar{v}_{t}$ : hourly mean truck speed</td>
<td></td>
</tr>
</tbody>
</table>

(Table Cont’d)
### Truck Volume

\[ q_t = \frac{q_{t,agg}}{k} \times 120 \]  \hspace{1cm} (9)

- \( q_t \): hourly truck volume
- \( q_{t,agg} \): hourly truck volume recorded over 108 days
- \( k \): hourly number of observations

### Total Truck Percentage

\[ P_t = \frac{q_t}{q_{total}} \times 100 \]  \hspace{1cm} (10)

- \( P_t \): total truck percentage
- \( q_t \): hourly truck volume
- \( q_{total} \): hourly total volume

### Lane Occupancy

\[ LO = \frac{LO_{sum}}{n} \times 120 \]  \hspace{1cm} (11)

- \( LO \): hourly occupancy
- \( LO_{sum} \): hourly sum of 30-second occupancies over 108 days
- \( n \): number of observations over 108 days

#### 5.2.1 Hourly Crash Rate

The reason for dividing the total volume by the number of observations was to eliminate the bias due to radar malfunctioning in some hours during the data collection period. For example, although RTMS 20 was operational between noon and 1 P.M.
August 8, 2007, it malfunctioned at 1:00:30 P.M. for an unknown reason, but was operational again at 1:30:30 P.M. The reported volume for the time period between 1 P.M. and 2 P.M. was less than the true hourly volume. Using the reported volume to calculate the crash rate would yield a higher crash rate value than the true value. Therefore, first, the 30-second volume was calculated and then it was scaled up to an hourly volume by multiplying it with 120.

5.2.2 Truck Percentage in the Left Lane / Difference between Car and Truck Hourly Mean Speeds

A significant difference between car and truck mean speeds may increase the likelihood of conflicts between cars and trucks due to fast cars hitting the slower moving trucks ahead. Although the implementation of differential speed limit alone may increase the probability of such conflicts, the implementation of right lane restriction together with the differential speed limit may help prevent conflicts between cars and trucks. In order to find the relationship between crash rate, lane restriction, and differential speed limit, the variables “truck percentage in the left lane” and “difference between car and truck hourly mean speeds” were included in the analysis.

5.2.3 Speed Limit Compliance

To investigate the impact of 55-mph truck speed limit and 60-mph car speed limit on crashes, two variables (truck percentage exceeding 55-mph and car percentage exceeding 60-mph) were obtained from the traffic data. The speeds reported by the RTMS devices were the average speed of all vehicles detected in a 30-second time interval. Therefore, the car and truck speeds were estimated for the time periods in
which both trucks and cars were detected by the RTMS devices (namely “mixed vehicle conditions”). The car speeds were estimated under the assumption that the car speed distribution for “cars-only” (the periods when the traffic stream contained only cars) free-flow conditions was similar to the car speed distribution for mixed vehicle free-flow conditions.

To determine the records indicating free-flow conditions, first, midsize vehicle volume and truck volume were converted to passenger car volumes. The passenger car equivalents (PCEs) for level terrain were obtained from the Highway Capacity Manual (HCM 2000). These were 1.2 for RVs and 1.5 for trucks. An RV was considered a midsize vehicle in this study. Since the traffic data reported truck volume for two different categories based on the length of trucks detected, a PCE of 1.5 was used to convert the truck volume reported in the field that was labeled as “long_truck”. HCM 2000 specified the free-flow condition as the rate of flow less than 1,300 passenger car per hour per lane or 10.8 passenger cars per 30-second per lane. Therefore, the records with a total PCE less than 10.8 passenger cars per 30-seconds per lane were selected as the records that indicated free-flow condition.

The records that indicated mixed vehicle free-flow and cars-only free-flow conditions were aggregated to five-minute intervals to reduce the variance in the 30-second speeds. The average speed of cars in a five-minute interval under mixed vehicle free-flow conditions was assumed to be equal to the average speed of cars under cars-only free-flow conditions in the same five-minute interval. The estimated car speeds for the mixed vehicle conditions were used to estimate the truck speeds under mixed vehicle conditions. The truck speeds were calculated from Equation 12.
\[ \bar{V}_{all} = (1 - P_t) \times \bar{V}_c + P_t \times \bar{V}_t \]  

(12)

where \( \bar{V}_{all} \) denoted the average speed of all vehicles in a five-minute interval under mixed vehicle free-flow conditions; \( P_t \) denoted the truck percentage in a five-minute interval under mixed vehicle free-flow conditions; \( \bar{V}_c \) denoted the average speed of cars in a five-minute interval under mixed vehicle free-flow conditions, and \( \bar{V}_t \) stood for the average speed of trucks in a five-minute interval under mixed vehicle free-flow conditions.

To use \( \bar{V}_c \) in Equation 12, it was assumed that the car speed under mixed vehicle free-flow conditions fluctuated around its mean with the same distance as the average speed of all vehicles under mixed vehicle free-flow conditions in terms of standard deviation. This assumption was formulated as follows:

\[ \frac{\bar{V}_c - \mu_c}{\sigma_c} = \frac{\bar{V}_{all} - \mu_{all}}{\sigma_{all}} \]  

(13)

where \( \bar{V}_c \) denoted the average car speed in a five-minute interval under mixed vehicle free-flow condition, \( \mu_c \) denoted the mean of five-minute car speeds under mixed vehicle free-flow condition, \( \sigma_c \) denoted the standard deviation of five-minute car speeds under mixed vehicle free-flow condition, \( \bar{V}_{all} \) denoted the average speed of all vehicles in a five-minute interval under mixed vehicle free-
flow condition, $\mu_{all}$ stood for the mean of five-minute speeds of all vehicles under mixed vehicle free-flow condition, while $\sigma_{all}$ denoted the standard deviation of five-minute average speeds of all vehicles under mixed vehicle free-flow condition.

After the truck and car speeds under mixed vehicle conditions were estimated, the truck speeds under trucks-only condition were aggregated to five-minute intervals and combined with the five-minute truck speeds under mixed vehicle condition. Finally, the variables truck percentage exceeding 55-mph and car percentage exceeding 60-mph were calculated using the formulas in Table 5.

To further investigate the relationship of high car and truck speeds with the crash rates, four more variables were included in the analysis: truck percentage exceeding 60-mph, truck percentage exceeding 65-mph, car percentage exceeding 65-mph, and car percentage exceeding 70-mph. The calculation of these variables was similar to the calculation of truck percentage exceeding 55-mph and car percentage exceeding 60-mph.

**5.2.4 Speed Variance**

A vehicle traveling at substantially high or low speeds is likely to be in a conflict with other vehicles traveling around the mean speed. To investigate the effect of increasing speed variance on the crash rate, two variables were included in the analysis: truck speed variance and car speed variance. Since truck speed limit is lower than the car speed limit, cars and trucks have different speed distributions. Therefore,
the variance for each distribution was calculated separately. The 30-second records when only trucks were detected in stream were aggregated into five-minute time intervals to maintain consistency with the five-minute truck speeds that were estimated for the mixed vehicle conditions.

5.2.5 Truck Exposure

Truck volume and total truck percentage were included in the analysis to evaluate the impact of truck exposure on crash rates. Similar to the calculation of the total volume, to eliminate the bias due to the radar malfunctioning during some hours, the hourly truck volume was divided by the number of 30-second observations and the resulting value was scaled up to an hourly volume.

5.2.6 Lane Occupancy

When the lane occupancy increases, the interaction between vehicles increases. Higher interaction among vehicles may increase the likelihood of crashes. To investigate if this was true, lane occupancy was included in the analysis.

5.3 Multiple Linear Regression Analysis

The relationship between the traffic characteristics and crash characteristics over the Atchafalaya Basin Bridge was investigated using multiple linear regression. Multiple linear regression is a technique that attempts to find a linear relationship between two or more explanatory variables and a response variable. There were two response variables in this study: (1) total crash rate, and (2) truck crash rate. The candidate explanatory variables are shown in Table 6.
The data used as input to the multiple regression procedure was grouped into 24 hourly observations. Each observation contained a value for the dependent variable and each of the candidate explanatory variables.

**Table 6. Candidate Explanatory Variables**

<table>
<thead>
<tr>
<th>Candidate Explanatory Variables</th>
<th>Candidate Explanatory Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck percentage in the left lane</td>
<td>Car percentage exceeding 70 mph</td>
</tr>
<tr>
<td>Difference between car and truck hourly mean speeds</td>
<td>Truck speed variance</td>
</tr>
<tr>
<td>Truck percentage exceeding 55 mph speed limit</td>
<td>Car speed variance</td>
</tr>
<tr>
<td>Truck percentage exceeding 60 mph</td>
<td>Total truck percentage</td>
</tr>
<tr>
<td>Truck percentage exceeding 65 mph</td>
<td>Truck volume</td>
</tr>
<tr>
<td>Car percentage exceeding 60 mph speed limit</td>
<td>Lane occupancy</td>
</tr>
<tr>
<td>Car percentage exceeding 65 mph</td>
<td>Container percentage exceeding 65 mph</td>
</tr>
</tbody>
</table>

Two procedures were followed to determine a linear relationship between crash rate and the traffic characteristics. The first procedure attempted to determine the variables that were significantly related to the crash rate at the 0.1 significance level; and the second procedure attempted to determine a combination of variables that together account for as much of the variance in the crash rate as possible. Both procedures also tested if one of the traffic characteristics affected another traffic characteristic’s relationship with the crash rate. The crash rate model that had the maximum R-square and that included independent variables all of which were significant at 0.1 level was selected as the final model. SAS statistical package was used in conducting the multiple linear regression analysis.
6. RESULTS AND ANALYSIS

This chapter presents the results and discussion of the multiple linear regression analysis conducted to investigate the relationship between traffic characteristics and crash characteristics in the presence of truck lane restriction and differential speed limit.

Since the bridge is a divided freeway, the crashes that happened in the eastbound and westbound directions of the bridge were analyzed. The analysis was also divided by day of week because trucks may have avoided traveling the bridge during certain hours of weekdays when the commuter volume on the bridge was high (i.e. during rush hours).

The regression analysis produced results for five cases characterized by the direction of traffic flow (eastbound/westbound) and the day of week (weekday/weekend) crashes happened in, and the involvement of trucks in crashes (truck-involved/total). On the other hand, none of the traffic characteristics were significantly related to the crash rates for the other three cases tested (total crashes that happened in the westbound direction of the bridge on weekdays, truck-involved crashes that happened in the eastbound direction of the bridge on the weekdays, and truck-involved crashes that happened in the westbound direction of the bridge on the weekdays). The following sections present an illustration of the regression procedure and describe the regression results for different cases.
6.1 Illustration of the Regression Analysis

This section presents an illustration of the regression procedure for the eastbound/weekday case. Table 7 shows the input data for this case. It contained 24 observations for total crash rate and all traffic characteristics considered in this study.

Table 7. Input Data for the Eastbound/Weekday Crash Analysis

<table>
<thead>
<tr>
<th>cr</th>
<th>$\sigma_{v,c}$</th>
<th>$\sigma_{v,t}$</th>
<th>$\bar{v}_c - \bar{v}_t$</th>
<th>LO</th>
<th>$P_{t \text{, left}}$</th>
<th>$P_t$</th>
<th>$q_t$</th>
<th>$P_c &gt; 60\text{-mph}$</th>
<th>$P_c &gt; 65\text{-mph}$</th>
<th>$P_c &gt; 70\text{-mph}$</th>
<th>$P_t &gt; 55\text{-mph}$</th>
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</table>

(Table Cont'd)
The first step in the procedure was to check for correlation between traffic characteristics. Table 8 shows the correlation coefficient for each pair of the traffic characteristics. A coefficient value greater than 0.7 was assumed to indicate a high correlation. As shown in the table, lane occupancy and truck volume, car percentage exceeding 65-mph and truck percentage exceeding 65-mph, car percentage exceeding 60-mph and car percentage exceeding 65-mph were highly correlated pairs.

The next step in the procedure was to identify the traffic characteristics that were significantly related to the crash rate at the 0.1 significance level. Table 9 shows the starting regression model for the backward elimination method, which was the first of the two methods utilized. As seen in the table, this method started with a model that contained all the independent variables.
### Table 8. Correlation Table for the Eastbound/Weekday Crash Analysis

<p>| Var.        | Int.  | $\sigma_{v,c}$ | $\sigma_{v,t}$ | $\bar{v}<em>c - \bar{v}<em>t$ | LO | $P</em>{t, \text{left}}$ | $P_t$ | $q_t$ | $P_c &gt; 60\text{-mph}$ | $P_c &gt; 65\text{-mph}$ | $P_c &gt; 70\text{-mph}$ | $P_c &gt; 55\text{-mph}$ | $P_t &gt; 60\text{-mph}$ | $P_t &gt; 65\text{-mph}$ | $P_t &gt; 70\text{-mph}$ | $P_t &gt; 55\text{-mph}$ |
|-------------|-------|----------------|----------------|--------------------------|----|----------------------|-------|-------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Int.        | 1.000 | -0.419         | -0.369         | 0.472                    | 0.673 | -0.244              | -0.405 | -0.656 | -0.625                  | 0.274                  | 0.217                  | 0.009                  | 0.266                  | -0.151                 |
| $\sigma</em>{v,c}$ | -0.419 | 1.000          | -0.228         | 0.137                    | -0.002 | -0.098              | -0.048 | 0.073   | 0.397                  | -0.222                  | -0.265                  | 0.130                  | -0.121                 | 0.283                 |
| $\sigma_{v,t}$ | -0.369 | -0.228         | 1.000          | -0.117                   | -0.287 | 0.114               | 0.120  | 0.456   | 0.298                  | -0.309                  | 0.196                  | -0.289                 | 0.138                  | 0.131                 |
| $v_c - v_t$  | 0.472  | 0.137          | -0.117         | 1.000                    | 0.567  | -0.241              | -0.407 | -0.391 | -0.065                  | -0.249                  | 0.052                  | 0.122                  | 0.026                  | 0.327                 |
| LO          | 0.673  | -0.002         | -0.287         | 0.567                    | 1.000  | 0.010               | -0.633 | -0.862 | -0.198                  | 0.253                  | -0.090                 | 0.333                  | 0.095                  | -0.186                |
| $P_{t, \text{left}}$ | -0.244 | -0.098         | 0.114          | -0.241                   | 0.010  | 1.000               | -0.241 | 0.081   | 0.352                  | -0.021                  | -0.207                 | 0.196                  | -0.406                 | -0.059                |
| $P_t$       | -0.405 | -0.048         | 0.120          | -0.407                   | -0.633 | -0.241              | 1.000  | 0.291   | 0.390                  | -0.345                  | 0.314                  | -0.552                 | -0.112                 | 0.198                 |
| $q_t$       | -0.656 | 0.073          | 0.456          | -0.391                   | -0.862 | 0.081               | 0.291  | 1.000   | 0.117                  | -0.244                  | -0.052                 | -0.178                 | -0.120                 | 0.270                 |
| $P_c &gt; 60\text{-mph}$ | -0.625 | 0.397          | 0.298          | -0.065                   | -0.198 | 0.352               | 0.390  | 0.117   | 1.000                  | -0.735                  | 0.210                  | -0.324                 | -0.247                 | 0.518                 |
| $P_c &gt; 65\text{-mph}$ | 0.274  | -0.222         | -0.309         | -0.249                   | 0.253  | -0.021              | -0.345 | -0.244 | -0.735                  | 1.000                  | -0.616                 | 0.605                  | 0.017                  | -0.831                |
| $P_c &gt; 70\text{-mph}$ | 0.217  | -0.265         | 0.196          | 0.052                    | -0.090 | -0.207              | 0.314  | -0.052 | 0.210                  | -0.616                  | 1.000                  | -0.617                 | 0.298                  | 0.316                 |
| $P_c &gt; 55\text{-mph}$ | 0.009  | 0.130          | -0.289         | 0.122                    | 0.333  | 0.196               | -0.552 | -0.178 | -0.324                  | 0.605                  | -0.617                 | 1.000                  | -0.531                 | -0.397                |
| $P_t &gt; 60\text{-mph}$ | 0.266  | -0.121         | 0.138          | 0.026                    | 0.095  | -0.406              | -0.112 | -0.247 | 0.017                  | 0.298                  | -0.531                 | 1.000                  | -0.246                 |                     |
| $P_t &gt; 65\text{-mph}$ | -0.151 | 0.283          | 0.131          | 0.327                    | -0.186 | -0.059              | 0.198  | 0.270   | 0.518                  | -0.831                  | 0.316                  | -0.397                 | -0.246                 | 1.000                 |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>Type II SS</th>
<th>F-Value</th>
<th>Pr &gt; F</th>
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</thead>
<tbody>
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<td>1354.944</td>
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<td>0.304</td>
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<td>462.496</td>
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<td>0.541</td>
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<td>0.182</td>
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<td>0.990</td>
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<tr>
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<tr>
<td>$P_{t &gt; 60-\text{mph}}$</td>
<td>30.238</td>
<td>73.612</td>
<td>194.529</td>
<td>0.170</td>
<td>0.690</td>
</tr>
<tr>
<td>$P_{t &gt; 65-\text{mph}}$</td>
<td>-67.324</td>
<td>70.935</td>
<td>1038.487</td>
<td>0.900</td>
<td>0.3649</td>
</tr>
</tbody>
</table>
Iteratively, it removed the least significant variable from the model until all the remaining variables were significant at 0.1 level. The result is shown in Table 10 and Table 11. The model in Table 10 did not show any sign of multicollinearity (correlation between independent variables).

Table 10. Reduced Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>Type II SS</th>
<th>F-value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>896.333</td>
<td>280.675</td>
<td>8858.175</td>
<td>10.200</td>
<td>0.005</td>
</tr>
<tr>
<td>$\tilde{v}_c - \bar{v}_t$</td>
<td>122.128</td>
<td>31.662</td>
<td>12924.000</td>
<td>14.880</td>
<td>0.001</td>
</tr>
<tr>
<td>$P_t$</td>
<td>-32.260</td>
<td>15.249</td>
<td>3887.685</td>
<td>4.480</td>
<td>0.048</td>
</tr>
<tr>
<td>$P_c &gt; 60$-mph</td>
<td>-13.756</td>
<td>4.143</td>
<td>9574.030</td>
<td>11.020</td>
<td>0.004</td>
</tr>
<tr>
<td>$P_t &gt; 55$-mph</td>
<td>33.306</td>
<td>14.223</td>
<td>4762.822</td>
<td>5.480</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Table 11. Eliminated Variables

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable Removed</th>
<th>Number of Variables Remaining in the Model</th>
<th>Partial R-Square</th>
<th>Model R-Square</th>
<th>C(p)</th>
<th>F-Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\sigma_{v,t}$</td>
<td>12</td>
<td>0.000</td>
<td>0.625</td>
<td>12.000</td>
<td>0.000</td>
<td>0.990</td>
</tr>
<tr>
<td>2</td>
<td>LO</td>
<td>11</td>
<td>0.001</td>
<td>0.625</td>
<td>10.022</td>
<td>0.020</td>
<td>0.881</td>
</tr>
<tr>
<td>3</td>
<td>$P_c &gt; 70$-mph</td>
<td>10</td>
<td>0.005</td>
<td>0.620</td>
<td>8.145</td>
<td>0.150</td>
<td>0.707</td>
</tr>
<tr>
<td>4</td>
<td>$q_t$</td>
<td>9</td>
<td>0.012</td>
<td>0.608</td>
<td>6.459</td>
<td>0.400</td>
<td>0.537</td>
</tr>
<tr>
<td>5</td>
<td>$P_t &gt; 60$-mph</td>
<td>8</td>
<td>0.013</td>
<td>0.596</td>
<td>4.798</td>
<td>0.450</td>
<td>0.512</td>
</tr>
<tr>
<td>6</td>
<td>$P_{t, left}$</td>
<td>7</td>
<td>0.040</td>
<td>0.556</td>
<td>3.851</td>
<td>1.460</td>
<td>0.245</td>
</tr>
<tr>
<td>7</td>
<td>$P_t &gt; 65$-mph</td>
<td>6</td>
<td>0.032</td>
<td>0.525</td>
<td>2.691</td>
<td>1.130</td>
<td>0.303</td>
</tr>
<tr>
<td>8</td>
<td>$\sigma_c$</td>
<td>5</td>
<td>0.018</td>
<td>0.507</td>
<td>1.173</td>
<td>0.640</td>
<td>0.433</td>
</tr>
<tr>
<td>9</td>
<td>$P_c &gt; 65$-mph</td>
<td>4</td>
<td>0.043</td>
<td>0.464</td>
<td>0.315</td>
<td>1.560</td>
<td>0.228</td>
</tr>
</tbody>
</table>
The R-square selection method determined models that contained two to seven traffic characteristics in different combinations, and ranked the models based on their R-square values. Tables 12 through 15 show the highest ranked ten models.

**Table 12. R-square Selection Results for the 7-variable Models**

<table>
<thead>
<tr>
<th>R-Square</th>
<th>7-variable models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Independent Variables</td>
</tr>
<tr>
<td>0.5804</td>
<td>$v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5761</td>
<td>$v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph, $P_t &gt; 60$-mph</td>
</tr>
<tr>
<td>0.5741</td>
<td>$\sigma_{v,c}$, $v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5736</td>
<td>$v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 70$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5734</td>
<td>$\sigma_{v,t}$, $v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5732</td>
<td>$v_c - v_t$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph, $P_t &gt; 65$-mph</td>
</tr>
<tr>
<td>0.5731</td>
<td>$v_c - v_t$, $LO$, $P_{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5667</td>
<td>$v_c - v_t$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph, $P_t &gt; 60$-mph</td>
</tr>
<tr>
<td>0.5571</td>
<td>$v_c - v_t$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph, $P_t &gt; 65$-mph</td>
</tr>
<tr>
<td>0.5565</td>
<td>$\sigma_{v,c}$, $v_c - v_t$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph</td>
</tr>
</tbody>
</table>
Table 13. R-square Selection Results for the 6-variable Models

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5729</td>
<td>$\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5522</td>
<td>$\bar{v}_c - \bar{v}<em>t$, LO, $P</em>{t, \text{left}}$, $P_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5521</td>
<td>$\bar{v}_c - \bar{v}_t$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5416</td>
<td>$\sigma_{v, c}$, $\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5384</td>
<td>$\sigma_{v, c}$, $\bar{v}_c - \bar{v}_t$, $P_t$, $P_c &gt; 60$-mph, $P_c &gt; 70$-mph, $P_t &gt; 60$-mph</td>
</tr>
<tr>
<td>0.5375</td>
<td>$\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $P_c &gt; 60$-mph, $P_c &gt; 70$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5358</td>
<td>$\bar{v}_c - \bar{v}_t$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_c &gt; 70$-mph, $P_t &gt; 60$-mph</td>
</tr>
<tr>
<td>0.5347</td>
<td>$\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $P_c &gt; 60$-mph, $P_c &gt; 65$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5335</td>
<td>$\sigma_{v, t}$, $\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $P_c &gt; 60$-mph, $P_t &gt; 55$-mph</td>
</tr>
<tr>
<td>0.5334</td>
<td>$\bar{v}_c - \bar{v}<em>t$, $P</em>{t, \text{left}}$, $P_t$, $q_t$, $P_c &gt; 60$-mph, $P_t &gt; 60$-mph</td>
</tr>
</tbody>
</table>
Table 14. R-square Selection Results for the 5-variable Models

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5308</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5198</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5138</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5114</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5065</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5042</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5041</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.501</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
<tr>
<td>0.5006</td>
<td>$\bar{v}_c - \bar{v}_t$</td>
</tr>
</tbody>
</table>
### Table 15. R-square Selection Results for the 4-variable Models

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4824</td>
<td>$\vec{v}_c - \vec{v}_t$</td>
</tr>
<tr>
<td>0.4637</td>
<td>$\vec{v}_c - \vec{v}_t$</td>
</tr>
<tr>
<td>0.4354</td>
<td>$\vec{v}_c - \vec{v}_t$</td>
</tr>
<tr>
<td>0.4142</td>
<td>$P_{t, left}$</td>
</tr>
<tr>
<td>0.4104</td>
<td>$P_{t, left}$</td>
</tr>
<tr>
<td>0.4076</td>
<td>$P_{t, left}$</td>
</tr>
<tr>
<td>0.4071</td>
<td>$\vec{v}_c - \vec{v}_t$</td>
</tr>
<tr>
<td>0.4069</td>
<td>$\sigma_{v, c}$</td>
</tr>
<tr>
<td>0.4067</td>
<td>$P_{t, left}$</td>
</tr>
</tbody>
</table>

Since the method did not report on the significance of each independent variable in a model, regression was performed on each model to determine whether all the variables in the models were significant. All five-, six-, and seven-variable models contained insignificant variables. The highest ranked model that did not contain any insignificant variable was a four-variable model. The R-square selection procedure produced a total of 120 models but the regression results for only the two highest ranked models are presented here due to the space limitations. Tables 16 through 22 present the regression results for models with four to seven variables. The selected four-variable model is same as the model that was found by the backward elimination method.
procedure; therefore both variable selection procedures produced consistent results.

Since this model did not show any sign of multicollinearity, it was chosen as the “main-effects” model.

Table 16. Regression Results for the Highest Ranked 7-variable Model

| R-Square | Variable        | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|-----------------|----|--------------------|----------------|---------|------|---|
| 0.580    | Intercept       | 1  | 670.083            | 385.273        | 1.740   | 0.101|
|          | $\bar{v}_c - \bar{v}_t$ | 1  | 90.491             | 40.409         | 2.240   | 0.040|
|          | $P_{t, left}$   | 1  | 40.798             | 39.279         | 1.040   | 0.314|
|          | $P_t$           | 1  | -78.585            | 27.466         | -2.860  | 0.011|
|          | $q_t$           | 1  | 2.408              | 1.824          | 1.320   | 0.205|
|          | $P_c > 60$-mph  | 1  | -17.005            | 9.075          | -1.870  | 0.079|
|          | $P_c > 65$-mph  | 1  | 3.274              | 6.151          | 0.530   | 0.602|
|          | $P_t > 55$-mph  | 1  | 65.806             | 27.321         | 2.410   | 0.028|

Table 17. Regression Results for the Second Highest Ranked 7-variable Model

| R-Square | Variable        | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|-----------------|----|--------------------|----------------|---------|------|---|
| 0.576    | Intercept       | 1  | 641.296            | 406.494        | 1.580   | 0.134|
|          | $\bar{v}_c - \bar{v}_t$ | 1  | 97.062             | 40.110         | 2.420   | 0.028|
|          | $P_{t, left}$   | 1  | 47.749             | 35.487         | 1.350   | 0.197|
|          | $P_t$           | 1  | -78.578            | 27.953         | -2.810  | 0.013|
|          | $q_t$           | 1  | 2.395              | 1.843          | 1.300   | 0.212|
|          | $P_c > 60$-mph  | 1  | -14.657            | 7.044          | -2.080  | 0.054|
|          | $P_t > 60$-mph  | 1  | 18.338             | 52.988         | 0.350   | 0.734|
|          | $P_t > 55$-mph  | 1  | 49.257             | 38.772         | 1.270   | 0.222|
### Table 18. Regression Results for the Highest Ranked 6-variable Model

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|---------|-------|---|
|          | Intercept| 1  | 554.483           | 311.475        | 1.780   | 0.093 |
| 0.573    | $\hat{v}_c - \hat{v}_t$ | 1  | 95.055            | 38.648         | 2.460   | 0.025 |
|          | $P_t$, left | 1  | 53.450            | 30.608         | 1.750   | 0.099 |
|          | $P_t$     | 1  | -76.563           | 26.623         | -2.880  | 0.011 |
|          | $q_t$     | 1  | 2.295             | 1.773          | 1.290   | 0.213 |
|          | $P_c > 60$-mph | 1 | -13.290           | 5.679          | -2.340  | 0.032 |
|          | $P_t > 55$-mph | 1 | 59.569            | 24.157         | 2.470   | 0.025 |

### Table 19. Regression Results for the Second Highest Ranked 6-variable Model

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|---------|-------|---|
|          | Intercept| 1  | 555.681           | 333.380        | 1.670   | 0.114 |
| 0.552    | $\hat{v}_c - \hat{v}_t$ | 1  | 94.911            | 40.390         | 2.350   | 0.031 |
|          | $P_t$, left | 1  | 44.478            | 31.766         | 1.400   | 0.179 |
|          | $P_t$     | 1  | -66.557           | 25.005         | -2.660  | 0.016 |
|          | LO       | 1  | 35.657            | 39.564         | 0.900   | 0.380 |
|          | $P_c > 60$-mph | 1 | -10.085           | 4.960          | -2.030  | 0.058 |
|          | $P_t > 55$-mph | 1 | 56.533            | 28.953         | 1.950   | 0.068 |
Table 20. Regression Results for the Second Highest Ranked 5-variable Model

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.531</td>
<td>Intercept 1</td>
<td>681.657</td>
<td>301.079</td>
<td>2.260</td>
<td>0.036</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{v}_c - \bar{v}_t$ 1</td>
<td>84.379</td>
<td>38.460</td>
<td>2.190</td>
<td>0.042</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{t \text{, left}}$ 1</td>
<td>49.815</td>
<td>31.046</td>
<td>1.600</td>
<td>0.126</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_t$ 1</td>
<td>-52.281</td>
<td>19.246</td>
<td>-2.720</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{c &gt; 60\text{-mph}}$ 1</td>
<td>-9.295</td>
<td>4.856</td>
<td>-1.910</td>
<td>0.072</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_t &gt; 55\text{-mph}$ 1</td>
<td>33.564</td>
<td>13.669</td>
<td>2.460</td>
<td>0.025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 21. Regression Results for the Second Highest Ranked 5-variable Model

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.519</td>
<td>Intercept 1</td>
<td>1165.390</td>
<td>330.206</td>
<td>3.530</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{v}_c - \bar{v}_t$ 1</td>
<td>87.671</td>
<td>33.729</td>
<td>2.600</td>
<td>0.018</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{c &gt; 70\text{-mph}}$ 1</td>
<td>7.507</td>
<td>6.341</td>
<td>1.180</td>
<td>0.252</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_t$ 1</td>
<td>-48.607</td>
<td>18.516</td>
<td>-2.630</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{c &gt; 60\text{-mph}}$ 1</td>
<td>-17.276</td>
<td>4.677</td>
<td>-3.690</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_t &gt; 60\text{-mph}$ 1</td>
<td>60.437</td>
<td>21.535</td>
<td>2.810</td>
<td>0.012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 22. Regression Results for the Highest Ranked 4-variable Model

| R-Square | Variable     | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|--------------|----|--------------------|----------------|---------|-------|------|
| 0.482    | Intercept    | 1  | 1057.183           | 320.642        | 3.300   | 0.004 |
|          | \( \bar{v}_c - \bar{v}_t \) | 1  | 111.561            | 27.311         | 4.080   | 0.001 |
|          | \( P_t \)    | 1  | -39.875            | 17.163         | -2.320  | 0.031 |
|          | \( P_c > 60\text{-mph} \) | 1  | -15.283            | 4.409          | -3.470  | 0.003 |
|          | \( P_t > 60\text{-mph} \) | 1  | 51.079             | 20.243         | 2.520   | 0.021 |

The next step in the regression analysis was to check for significant relationship between the crash rate and the interaction of any two independent variables in the main-effects model. Two procedures were followed to achieve this. The first procedure, stepwise selection, added the interaction terms to the main-effects model one at a time and performed regression on the model. As shown in Table 23, one of the interaction terms was significant, but it made one of the main-effect variables insignificant. Since the goal of the analysis was to determine a relationship between traffic characteristics and crash rate at the 0.1 significance level, the model shown in Table 23 could not be selected as the final model.
Table 23. Results of the Stepwise Selection Procedure for Testing the Significance of Interaction Terms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>Type II SS</th>
<th>F-Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1413.185</td>
<td>361.141</td>
<td>11461.000</td>
<td>15.310</td>
<td>0.001</td>
</tr>
<tr>
<td>$\bar{v}_c - \bar{v}_t$</td>
<td>-491.271</td>
<td>333.818</td>
<td>1621.075</td>
<td>2.170</td>
<td>0.158</td>
</tr>
<tr>
<td>$P_t$</td>
<td>-51.374</td>
<td>17.415</td>
<td>6513.437</td>
<td>8.700</td>
<td>0.009</td>
</tr>
<tr>
<td>$P_c &gt; 60$-mph</td>
<td>-20.317</td>
<td>5.008</td>
<td>12318.000</td>
<td>16.460</td>
<td>0.001</td>
</tr>
<tr>
<td>$P_t &gt; 60$-mph</td>
<td>61.905</td>
<td>20.040</td>
<td>7142.704</td>
<td>9.540</td>
<td>0.006</td>
</tr>
<tr>
<td>$(\bar{v}_c - \bar{v}_t) \cdot (P_c &gt; 60$-mph)</td>
<td>11.704</td>
<td>6.462</td>
<td>2455.594</td>
<td>3.280</td>
<td>0.087</td>
</tr>
</tbody>
</table>

The second procedure, backward elimination, found two significant interaction terms as shown in Table 24 after eliminating the interaction terms shown in Table 25. However the model shown in Table 24 cannot be considered a candidate for the final model because one of the main-effect variables became insignificant when the interaction terms were in the model.

None of the two selection methods that were utilized yielded a model with interaction terms in which all the variables were significant; therefore, the main-effects model became the final model. The next sections describe the five final regression models that were obtained for different cases characterized by truck involvement in crash, day of week, and direction of crash. The illustration of the regression procedure is not repeated for the other four cases, but rather the final results are presented and discussed. Two-way interactions between the independent variables of the main effect
models were tested for significance; however some of the interaction terms were not significantly related to the crash rates at 0.1 level, and some caused the main effect terms to become insignificant when they entered the model. Therefore, the interaction terms were not included in the final models; the main effects model was also the final regression model for each case.

Table 24. Results of the Backward Elimination Procedure for Testing the Significance of Interaction Terms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>Type II SS</th>
<th>F-Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2355.663</td>
<td>829.853</td>
<td>5348.146</td>
<td>8.060</td>
<td>0.011</td>
</tr>
<tr>
<td>$\bar{v}_c - \bar{v}_t$</td>
<td>346.787</td>
<td>92.261</td>
<td>9377.022</td>
<td>14.130</td>
<td>0.002</td>
</tr>
<tr>
<td>$P_t$</td>
<td>-139.255</td>
<td>52.868</td>
<td>4604.813</td>
<td>6.940</td>
<td>0.017</td>
</tr>
<tr>
<td>$P_c &gt; 60$-mph</td>
<td>-46.172</td>
<td>17.846</td>
<td>4442.567</td>
<td>6.690</td>
<td>0.019</td>
</tr>
<tr>
<td>$P_t &gt; 60$-mph</td>
<td>20.273</td>
<td>23.446</td>
<td>496.264</td>
<td>0.750</td>
<td>0.399</td>
</tr>
<tr>
<td>$(\bar{v}_c - \bar{v}_t) * (P_t &gt; 60$-mph)</td>
<td>-29.313</td>
<td>11.373</td>
<td>4408.651</td>
<td>6.640</td>
<td>0.020</td>
</tr>
<tr>
<td>$(P_t) * (P_c &gt; 60$-mph)</td>
<td>2.552</td>
<td>1.271</td>
<td>2675.942</td>
<td>4.030</td>
<td>0.061</td>
</tr>
</tbody>
</table>

Table 25. Eliminated Interaction Terms in the Backward Elimination Procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Variables Removed</th>
<th>Number of Variables Remaining in the Model</th>
<th>Partial R-Square</th>
<th>Model R-Square</th>
<th>C(p)</th>
<th>F-Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$(P_c &gt; 60$-mph) * $(P_t &gt; 60$-mph)</td>
<td>9</td>
<td>0.000</td>
<td>0.704</td>
<td>9.009</td>
<td>0.010</td>
<td>0.926</td>
</tr>
</tbody>
</table>
6.2 Description of the Final Regression Models

6.2.1 All Crashes on Weekdays in Eastbound

This section presents the regression analysis results for all crashes that happened on weekdays in the eastbound direction of flow. The multiple linear regression analysis yielded a crash rate model that included four independent variables: difference between car and truck hourly mean speeds, total truck percentage, car percentage exceeding 60-mph, and truck percentage exceeding 60-mph. The R-square value, shown in Table 26, suggested that these variables collectively explained 48 percent of the variation in the crash rate. As indicated by the p-values in Table 26, all the independent variables were significantly related to the crash rate at the 0.05 level.

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.482</td>
<td>Intercept</td>
<td>1</td>
<td>1057.183</td>
<td>320.642</td>
<td>3.300</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{v}_c - \bar{v}_t$</td>
<td>1</td>
<td>111.561</td>
<td>27.311</td>
<td>4.080</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

(Table Cont'd)
A coefficient value of 51 for the variable “percentage of trucks exceeding 60-mph” indicated that the crash rate increased by 51 crashes per 100 million vehicle-miles when there was one percent increase in the percentage of trucks exceeding 60-mph. In contrast to this result, the scatter plot of the hourly crash rate and the variable “percentage of trucks exceeding 60-mph” did not show any correlation in Figure 7. In fact, when the crash rate was regressed only on this variable, the p-value for the variable increased to 0.6548 which indicated that there was no significant relationship between the crash rate and the percentage of trucks exceeding 60-mph. Furthermore, the R-square value of this simple regression model was as small as 0.0093, pointing out that only one percent of the variation in the crash rate was explained by this variable.

Table 27. Simple Regression Results for Cars Exceeding the 60-mph Speed Limit

| R-Square | Variable       | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------------|----|--------------------|----------------|---------|-------|---|
| 0.0093   | Intercept      | 1  | 63.0496            | 22.1948        | 2.84    | 0.0095|
|          | $P_t > 60$-mph | 1  | 0.69003            | 1.5222         | 0.45    | 0.6548|

The difference in the p-values in the simple and multiple linear regression analyses suggested that the addition of other variables into the regression model reduced this variable’s share in explaining the variation in the crash rate, which resulted
in an increase of the variable’s p-value from 0.021 to 0.6548. In essence, the variable was not related to the crash rate significant enough to explain the variation in the crash rate by itself.

Figure 7. The Scatter Plot of Truck Percentage Exceeding 60-mph and Total Crash Rate

A coefficient value of 15 for the variable car percentage exceeding 60-mph indicated that the crash rate increased by 15 crashes per 100 million vehicle-miles when the percentage of cars traveling over 60-mph increased by one percent. On the other hand, the scatter plot diagram of the crash rate and car speed data did not show any sign of a relationship. Regressing the crash rate only on the variable “car percentage exceeding 60-mph” resulted in a model with an R-square value as low as 0.0197, and a p-value of 0.5132 which indicated that there was no significant relationship between the independent and dependent variables at the 0.1 level.
Table 28. Simple Regression Results for Cars Exceeding 60-mph

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|------|------|
| 0.0197   | Intercept| 1  | 165.8515           | 140.6481       | 1.18    | 0.2509 |
|          | $P_c > 60$-mph | 1  | -1.7847            | 2.6852         | -0.66   | 0.5132 |

Figure 8. The Scatter Plot of Car Percentage Exceeding 60-mph and Total Crash Rate

Consistent with the findings from the multiple regression analysis of the weekend total crashes, an increasing difference between car and truck mean speeds was significantly related to the total crash rate, as indicated by the regression coefficient of the mean speed differential in the multiple regression model. As suggested by the coefficient, one mile per hour increase in the mean speed differential was associated
with 112 crashes per 100 million vehicle-miles increase in the crash rate. This result was in contrast with the results from the preliminary analysis that showed no sign of a relationship in the scatter plot of the data. Furthermore, the regression of the crash rate only on the mean speed differential produced a p-value of 0.2420 which showed that there was no significant relationship at the 0.1 level. The results from these preliminary analyses are shown in Figure 9 and Table 29.

Table 29. Simple Regression Results for Difference between Car and Truck Mean Speeds

| R-Square | Variable     | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|--------------|----|--------------------|----------------|---------|-------|---|
| 0.0617   | Intercept    | 1  | 65.3117            | 9.5108         | 6.87    | <0.0001|
|          | \(\bar{v}_c - \bar{v}_t\) | 1  | 21.8087            | 18.1369        | 1.20    | 0.2420|

Figure 9. The Scatter Plot of Difference between Car and Truck Hourly Mean Speeds and Total Crash Rate
On the other hand, the multiple regression analysis found that when the percentage of trucks in the traffic stream increased, the crash rate decreased. For each percent increase in the total truck percentage, the reduction in the crash rate was 112 crashes per 100 million vehicle-miles. As opposed to this result, the scatter plot diagram showed dispersion in Figure 10, and the simple regression on the total truck percentage produced a p-value of 0.5771, which indicated that there was no significant relationship at the 0.1 significance level.

### Table 30. Simple Regression Results for Total Truck Percentage

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|-------|---|
| 0.0144   | Intercept| 1  | 54.53489           | 32.63644       | 1.67    | 0.1089|
|          | P_t      | 1  | 0.96465            | 1.70425        | 0.57    | 0.5771|

![Figure 10. The Scatter Plot Diagram of Total Truck Percentage and Total Crash Rate](image)

![Image of a scatter plot diagram showing the relationship between hourly total truck percentage and hourly number of crashes per 100 million vehicle-miles.]
The low R-square values for the simple regression on each of the traffic characteristics suggested that it was not surprising to obtain an R-square value as low as 0.45 for the weekend/westbound total crash rate model, because the R-square value of a multiple regression model indicates the cumulative ability of all variables in the model to explain the variation in the crash rate.

6.2.2 All Crashes on Weekends in Eastbound

This section presents the regression analysis results for all crashes that happened on the weekends in the eastbound direction of flow. The multiple regression analysis yielded a crash rate model that included six independent variables: occupancy, difference between car and truck hourly mean speeds, truck volume, total truck percentage, and truck percentage exceeding 60-mph. All the independent variables were significantly related to the crash rate at the 0.05 level, as indicated by the p-values in Table 31. It is also shown that the R-square of the model was 0.4368. This indicates that the independent variables collectively accounted for 44 percent of the variation in the crash rate. This is reasonable, because the individual ability of the variables in explaining the variation in the crash rate was relatively low. These findings are presented in the following paragraphs.

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t|
|----------|----------|----|--------------------|----------------|---------|-------|
| 0.437    | Intercept| 1  | 3384.656           | 2373.087       | 1.430   | 0.171 |
|          | LO       | 1  | 685.153            | 244.567        | 2.800   | 0.012 |

(Table Cont'd)
A coefficient value of 257 for the variable “difference between car and truck hourly mean speeds” indicated that an increasing difference in the mean speeds was associated with an increasing total crash rate. More particularly, it suggested that when the speed difference between cars and trucks increased by one mile per hour, the crash rate increased by 257 crashes per 100 million vehicle-miles. In contrast to the results from the multiple regression analysis, the scatter plot of the crash rate and mean speed differential data did not show any correlation in Figure 11. Furthermore, when the crash rate was regressed only on the mean speed differential, the p-value of the variable increased to 0.5598, indicating that there was no significant relationship between crash rate and mean speed differential at the 0.1 level. This is shown in Table 32. Furthermore, the R-square value of 0.0157 indicated a poor model fit for the simple regression model.

Table 32. Simple Regression Results for the Difference between Car and Truck Mean Speeds

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t|
|----------|----------|----|--------------------|----------------|---------|-------|
| 0.0157   | Intercept | 1  | 239.13255          | 70.56717       | 3.39    | 0.0026 |
|          | $\bar{v}_c - \bar{v}_t$ | 1  | 33.67422           | 56.87312       | 0.59    | 0.5598 |
A coefficient of 425 for the variable “truck percentage exceeding 60-mph” indicated that the hourly crash rate increased by 425 crashes per 100 million vehicle-miles with each percent of trucks exceeding 60-mph. As in the case of the variable “difference between car and truck hourly mean speeds”, the scatter plot of the data did not show any sign of correlation between the crash rate and the truck speed. Furthermore, the p-value in Table 33, which was greater than 0.1, indicated that there was no significant linear relationship between the crash rate and the trucks traveling over 60-mph when the crash rate was regressed only on this variable.
Table 33. Simple Regression Results for Trucks Exceeding 60-mph

| R-Square | Variable   | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|------------|----|--------------------|----------------|---------|------|---|
| 0.0054   | Intercept  | 1  | 234.36867          | 118.28037      | 1.98    | 0.0602|
|          | $P_t > 60$-mph | 1  | 3.69179            | 10.73040       | 0.34    | 0.7341|

Figure 12. The Scatter Plot Diagram of Truck Percentage Exceeding 60-mph and the Total Crash Rate

The regression coefficient for “truck volume” indicated that when the hourly truck volume increased by one vehicle, a reduction of 41 crashes per 100 million vehicle-miles was observed in the total crash rate. Figure 13 and Table 34 show the scatter plot diagram and the results from the regression of crash rate only on this variable. In contrast to the result from the multiple regression analysis, the scatter plot of the data did not show any sign of a relationship. The simple regression result showed that there
was no significant relationship between crash rate and truck volume based on a p-value of 0.5270. Furthermore, the R-square was as low as 0.0184.

Table 34. Simple Regression Results for Truck Volume

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|---------|-------|-----|
| 0.0184   | Intercept| 1  | 715.98461         | 691.61673      | 1.04    | 0.3118|
|          | q_t      | 1  | -2.87299          | 4.46919        | -0.64   | 0.5270|

Figure 13. The Scatter Plot Diagram of Truck Volume and the Total Crash Rate

As indicated by the regression coefficient for the total truck percentage in the multiple regression model, a reduction in the crash rate occurred when the percentage of trucks in the stream increased. Table 27 suggests that when the truck percentage
increased by one percent of the total volume, the crash rate decreased by 196 crashes per 100 million vehicle-miles. This result suggested that the interaction between trucks and cars created accident prone conditions. On the other hand, Figure 14 showed no sign of correlation between crash rate and the percentage of trucks in the traffic stream. Consistent with the descriptive results, the p-value in Table 35 indicated no significant relationship when the crash rate was only regressed on total truck percentage.

**Table 35. Simple Regression Results for the Total Truck Percentage**

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|-------|
| 0.0046   | Intercept| 1  | 228.04481          | 145.42069      | 1.57    | 0.1311|
|          | Pt       | 1  | 3.24219            | 10.18407       | 0.32    | 0.7532|

**Figure 14. The Scatter Plot of the Total Truck Percentage and the Total Crash Rate**

As indicated by the regression coefficient for the lane occupancy in the multiple regression model, one percent increase in the lane occupancy was associated with an increase of 685 crashes per 100 million vehicle-miles in the crash rate. This suggested
that the likelihood of a crash increased as the interaction between vehicles increased. However, the scatter plot of the crash rate and lane occupancy data did not show any sign of correlation between the two variables. Furthermore, the p-value for the lane occupancy when it was left as the only variable in the regression model was 0.0104, which indicated that there was no significant relationship between crash rate and this variable. These results from the preliminary analysis of the data are shown in Figure 15 and Table 36.

**Table 36. Simple Regression Results for Lane Occupancy**

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0104</td>
<td>Intercept</td>
<td>1</td>
<td>336.52933</td>
<td>140.53186</td>
<td>2.39</td>
<td>0.0256</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LO</td>
<td>1</td>
<td>-18.38479</td>
<td>38.24720</td>
<td>-0.48</td>
<td>0.6355</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 15. The Scatter Plot of the Lane Occupancy and the Total Crash Rate**
6.2.3 All Crashes on Weekends in Westbound

This section presents the regression analysis results for all crashes that happened on weekends in the westbound direction of flow. The multiple linear regression analysis produced a crash rate model that included two independent variables: total truck percentage, and truck percentage in left lane. As shown in Table 28, these variables explained 45 percent of the variation in the crash rate. The p-values in Table 28 indicated that the variables were significant at the 0.1 significance level.

Table 37. Multiple Regression Results for All Crashes on Weekends in the Westbound Direction of Flow

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.447</td>
<td>Intercept</td>
<td>1</td>
<td>53.924</td>
<td>25.210</td>
<td>2.140</td>
<td>0.044</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P_t, left</td>
<td>1</td>
<td>39.601</td>
<td>15.576</td>
<td>2.540</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P_t</td>
<td>1</td>
<td>-15.471</td>
<td>8.011</td>
<td>-1.930</td>
<td>0.067</td>
<td></td>
</tr>
</tbody>
</table>

Consistent with the findings for the eastbound crashes, the multiple regression results showed that the total crash rate on weekends in the westbound direction of flow decreased with an increasing truck percentage. The regression coefficient for the variable “total truck percentage” in Table 37 showed that the reduction in the crash rate was 16 crashes per 100 million vehicle-miles with every percent increase in the total truck percentage. On the other hand, the scatter plot of the truck percentage and crash rate data showed dispersion. The simple regression on the total truck percentage
yielded a p-value lower than 0.1; therefore the total truck percentage by itself was found to be significantly related to total crash rate. Furthermore, the R-square of the simple regression model, as shown in Table 38, was higher than the R-square values for the other simple regression models discussed earlier. However, the signs of the regression coefficients in multiple and simple regression models were different. When no variable was controlled for, total truck percentage was positively correlated with the crash rate. However, when the truck percentage in the left lane was controlled for, the total truck percentage was negatively correlated with the crash rate. This finding suggested that an increasing truck percentage in the right lane was associated with reduction in the crash rate.

Table 38. Simple Regression Results for Total Truck Percentage

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|-------|------|
| 0.2768   | Intercept| 1  | 2.63562            | 16.89323       | 0.16    | 0.8774|
|          | $P_t$    | 1  | 4.57851            | 1.57765        | 2.90    | 0.0083|

Figure 16. The Scatter Plot Diagram of Total Truck Percentage and Total Crash Rate
The coefficient for left lane truck percentage in the multiple regression model indicated that when the percentage of trucks in the left lane increased by one percent of the hourly total volume, the hourly crash rate increased by 39 crashes per 100 million vehicle-miles. The result from the multiple linear regression analysis was consistent with the result from the preliminary analysis. The scatter plot of the left lane truck percentage and crash rate data showed an upward trend as seen in Figure 17, indicating a sign of a positive relationship. Also, Table 39 showed that the p-value for the left lane truck percentage was 0.0024 when the crash rate was regressed only on this variable. Since the p-value was below 0.1, the simple regression result indicated a significant relationship between crash rate and the left lane truck percentage. The R-square of the model was 0.35. This was the highest R-square value obtained for the simple regression models in this study. Further, the positive slope of the regression equation showed consistency with the coefficient for this variable in the multiple regression model.

Table 39. Simple Regression Results for Truck Percentage in the Left Lane

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|---------------|---------|-------|---|
| 0.3489   | Intercept| 1  | 10.63682           | 12.23131      | 0.87    | 0.3939|
|          | P<sub>t</sub>,left | 1  | 9.99269            | 2.91066       | 3.43    | 0.0024|
6.2.4 Truck-involved Crashes on Weekends in Eastbound

This section presents the regression analysis results for the truck-involved crashes that happened on weekends in the eastbound direction of flow. The multiple regression analysis yielded a crash rate model that included four independent variables: truck speed variance, total truck percentage, occupancy, and truck percentage exceeding 60-mph. As shown in Table 40, all four variables were related to the crash rate at the 0.1 significance level. The R-square of the model indicated that these variables accounted for 51 percent of the variation in the crash rate.
Table 40. Multiple Regression Results for Crashes Involving Trucks on Weekends in the Eastbound Direction of Flow

| R-Square | Variable     | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|--------------|----|--------------------|----------------|---------|-------|
| 0.513    | Intercept    | 1  | -835.736           | 337.237        | -2.480  | 0.023 |
|          | $\sigma_{v,t}$ | 1  | 11.133             | 5.908          | 1.880   | 0.075 |
|          | LO           | 1  | 171.768            | 68.404         | 2.510   | 0.021 |
|          | $P_t$        | 1  | -124.118           | 31.124         | -3.990  | 0.001 |
|          | $P_t > 60$-mph | 1 | 229.874            | 57.222         | 4.020   | 0.001 |

As indicated by the regression coefficient for the variable “percentage of trucks exceeding 60-mph”, the truck-involved crash rated increased when trucks traveled over 60-mph. The increase was 230 crashes per 100 million vehicle-miles for each percent increase in the percentage of trucks exceeding 60-mph. In contrast to this relationship, Figure 18 showed dispersion in the scatter plot of the crash rate and truck percentage exceeding 60-mph. Another result from the preliminary analysis that contradicted with the multiple regression analysis results was the p-value of 0.2465 indicating that there was no significant relationship between crash rate and trucks traveling over 60-mph. Table 41 presents the results from this simple regression. The R-square value as low as 0.0605 was not surprising since a high p-value was obtained.

Table 41. Simple Regression Results for Trucks Exceeding 60-mph

| R-Square | Variable     | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|--------------|----|--------------------|----------------|---------|-------|
| 0.0605   | Intercept    | 1  | -16.76616          | 53.27543       | -0.31   | 0.7559|
|          | $P_t > 60$-mph | 1 | 5.75445           | 4.83315        | 1.19    | 0.2465|
The crash rate also increased when the truck speed variance increased. Every unit increase in the truck speed variance was associated with 11 crashes per 100 million vehicle-miles, as indicated by the coefficient of truck speed variance in the multiple regression model. On the other hand, Table 42 showed that when the crash rate was regressed only on this variable, the p-value increased to a value above 0.1, making the relationship insignificant. Furthermore, the value of R-square decreased from 0.513 to 0.0092, which indicated a poor fit. Figure 19 shows the dispersion in the scatter plot of the crash rate and truck speed variance data.

Table 42. Simple Regression Results for Truck Speed Variance

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|---------|--------|-----|
| 0.0092   | Intercept | 1  | -3.44816          | 103.37253       | -0.03   | 0.9737 |
|          | \(_{\sigma_{ts}}\) | 1  | 2.68563           | 5.95777         | 0.45    | 0.6566 |
Another traffic characteristic that was positively related to the crash rate was the lane occupancy. Table 40 shows that when the lane occupancy increased by one percent, 172 crashes occurred every 100 million vehicle-miles. This result suggested that an increasing interaction between vehicles increased the likelihood of a conflict. On the other hand, the scatter plot diagram of the two variables was dispersed, as shown in Figure 20. In fact, when the lane occupancy was the only variable in the model, the p-value for this variable increased to 0.2957, explaining the dispersion seen in the scatter plot diagram.

**Table 43. Simple Regression Results for Lane Occupancy**

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|-------|-----|
| 0.0496   | Intercept| 1  | 107.33489          | 63.82817       | -1.68   | 0.1068|
|          | LO       | 1  | -18.60779          | 17.37150       | -1.07   | 0.2957|
On the other hand, multiple regression analysis found that an increasing total truck percentage was related to a declining crash rate. As indicated by the regression coefficient of the variable in Table 40, when the total truck percentage increased by five percent, the crash rate decreased by 124 crashes per 100 million vehicle-miles. However, the scatter plot of the data did not show any trend in Figure 21. Furthermore, when the crash rate was regressed on the truck percentage alone, the p-value increased to 0.3104, and the R-square value of the model decreased to 0.0467, as shown in Table 44.

**Table 44. Simple Regression Results for Total Truck Percentage**

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|---------|-------|-----|
| 0.0467   | Intercept| 1  | -23.11554         | 65.95417       | -0.35   | 0.7293|
|          | $P_t$    | 1  | 4.79634           | 4.61889        | -1.04   | 0.3104|
6.2.5 Truck-involved Crashes on Weekends in Westbound

This section presents the regression analysis results for the truck-involved crashes that happened on the weekends in the westbound direction of flow. The multiple linear regression analysis yielded a crash rate model that included five independent variables, all significant at the 0.05 level: truck volume, total truck percentage, truck percentage in the left lane, truck percentage exceeding 55-mph, and car percentage exceeding 60-mph. The independent variables collectively explained 53 percent of the variation in the crash rate.
Table 45. Regression Results for Crashes Involving Trucks on Weekends in the Westbound Direction of Flow

| R-Square | Variable     | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|--------------|----|--------------------|----------------|---------|------|-----|
| 0.531    | Intercept    | 1  | -1856.839          | 660.706        | -2.810  | 0.012|
|          | P_{t, left}  | 1  | 169.361            | 54.762         | 3.090  | 0.006|
|          | P_{t}        | 1  | -152.120           | 52.661         | -2.890 | 0.010|
|          | q_{t}        | 1  | 16.268             | 4.315          | 3.770  | 0.001|
|          | P_{c} > 60-mph| 1 | -16.812            | 5.552          | -3.030 | 0.007|
|          | P_{t} > 55-mph | 1 | 148.895           | 45.158         | 3.300  | 0.004|

The coefficient of left lane truck percentage in the multiple regression model indicated that the crash rate increased with an increase in the left lane truck percentage. Table 45 shows that when the left lane truck percentage increased by two percent of the total volume, the hourly crash rate increased by 339 crashes per 100 million vehicle-miles. In contrast, the preliminary analysis results did not indicate a relationship between crash rate and left lane truck percentage. 48 percent of the data points in the scatter plot diagram of the left lane truck percentage and crash rate indicated zero crash rate. On the other hand, Table 46 shows that a simple linear regression on the left lane truck percentage produced a p-value higher than 0.1, which indicated that there was no significant relationship between crash rate and the percentage of trucks in the left lane. Furthermore, the R-square of the simple regression model was 0.1088, which showed that the regression line had a poor fit.
The truck speed limit violation was another factor that had a positive relationship with the crash rate, as suggested by the multiple regression model. The coefficient of the variable “truck percentage exceeding 55-mph” indicated that the crash rate increased by 149 crashes per 100 million vehicle-miles with each percent increase in the percentage of trucks traveling over 55-mph. The scatter plot of the data showed that 50 percent of the data points indicated an upward trend, however the other 50 percent indicated zero crash rate. The simple regression results shown in Table 47 indicated...
that there was no significant relationship between crash rate and the percentage of trucks traveling over the speed limit.

Table 47. Simple Regression for Trucks Traveling over the 55-mph Speed Limit

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Variable</th>
<th>DF</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1010</td>
<td>Intercept</td>
<td>1</td>
<td>12.08302</td>
<td>37.64380</td>
<td>0.32</td>
<td>0.7513</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_t &gt; 55$-mph</td>
<td>1</td>
<td>7.81650</td>
<td>4.97095</td>
<td>1.57</td>
<td>0.1301</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 23. The Scatter Plot of Truck Percentage Exceeding 55-mph and Truck-involved Crash Rate

On the other hand, the multiple regression model suggested that cars traveling over 60-mph was related to a declining crash rate. Table 45 shows that when the car percentage exceeding 60-mph increased by four percent of the hourly total volume, the hourly crash rate decreased by 67 crashes per 100 million vehicle-miles. However, Figure 24 showed that the scatter plot diagram of the car speed and crash data did not show a clear trend. Furthermore, the regression of crash rate on the car percentage
exceeding 60-mph found that there was no significant relationship between the two variables; and the model had a poor fit. Table 48 shows the result of this analysis.

Table 48. Simple Regression Results for Cars Traveling over the 60-mph Speed Limit

| R-Square | Variable    | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|-------------|----|--------------------|----------------|---------|-------|----|
| 0.0000   | Intercept   | 1  | 72.86388           | 263.50513      | 0.28    | 0.7847|
|          | P_c > 60-mph| 1  | -0.13109           | 5.36646        | -0.02   | 0.9807|

Figure 24. The Scatter Plot of Car Percentage Exceeding 60-mph and Truck-involved Crash Rate

The regression coefficient for the variable “total truck percentage” in the multiple regression model indicated that when the total truck percentage increased by one percent, the truck-involved crash rate decreased by 152 crashes per 100 million vehicle-miles. On the other hand, the scatter plot of the data showed that 54 percent of the data points showed a positive relationship while 46 percent of the data points indicated zero crash rate. However when the crash rate was regressed only on the total truck
percentage, a p-value greater than 0.1 was obtained, which indicated that there was no significant relationship between crash rate and the total truck percentage. As shown in Table 49, the R-square value of the simple regression model was as small as 0.0952, indicating a poor model fit.

Table 49. Simple Regression Results for Total Truck Percentage

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|--------------------|----------------|---------|-------|---|
| 0.0952   | Intercept| 1  | -11.61592          | 53.43984       | -0.22   | 0.8299|
|          | P_t      | 1  | 7.59272            | 4.99072        | 1.52    | 0.1424|

The coefficient of the variable “truck volume” in the multiple regression model indicated that every truck that joined the stream was associated with a crash rate increasing at a rate of 16 crashes per 100 million vehicle-miles. However, the scatter plot of the truck volume and crash rate data did not indicate any sign of a relationship. The regression of crash rate only on the truck volume found a p-value of 0.2966,
indicating that there was no significant relationship between these two variables. As shown in Table 50, the R-square value of 0.0464 showed that the model had a poor fit.

Table 50. Simple Regression Results for Truck Volume

| R-Square | Variable | DF | Parameter Estimate | Standard Error | t-value | Pr > |t| |
|----------|----------|----|-------------------|----------------|--------|-------|---|
| 0.0494   | Intercept| 1  | 262.71058         | 184.21848      | 1.43   | 0.1679|
|          | q_t      | 1  | -1.22165          | 1.14265        | -1.07  | 0.2966|

Figure 26. The Scatter Plot of Truck Volume and Truck-involved Crash Rate
7. CONCLUSION AND RECOMMENDATIONS

This study investigated the relationship between crash rate and traffic characteristics on a rural four-lane elevated freeway that operates under right lane truck restriction and differential speed limit. The traffic characteristics used in the analysis included lane restriction compliance, speed limit compliance, difference between car and truck mean speeds, truck speed variance, truck percentage, and lane occupancy.

The analyses in this study are unique in that there are no other examples of analyses that compared crash and traffic characteristics under truck lane restriction and differential speed limit. Also, the study section is the first elevated freeway that operates under both lane restriction and differential speed limit.

The results of multiple regression analyses showed that when trucks violated the lane restriction, crash rates increased. This finding is consistent with the results reported by majority of the studies that were reviewed.

On the other hand, the relationship between differential speed limit policy and crash rates was not clear, because the inverse relationship between crash rates and the percentage of cars exceeding the car speed limit was unreasonable. Such a counter-intuitive result could be due to the limitations of the study. One of the limitations was that the truck and car speeds were estimated for conditions when both vehicles were detected in the stream, because the RTMS devices provided speed of all vehicles that were detected in each 30-second time interval. The other limitation of the study was that crash and traffic data collection were not performed concurrently; therefore the
comparison of the characteristics from the crash and traffic data required an assumption to be made. It was assumed that the observed traffic conditions during data collection period were representative of the prevailing traffic conditions at the crash time and location. Due to these limitations, the findings of the study may be used to compare the crash and traffic characteristics on the Atchafalaya Basin Bridge only.

An interesting finding in the study was that the multiple regression models were capable of explaining only about 50 percent of the variation in the crash rates, and the capability of each traffic characteristic individually was even less than 12 percent except in two cases in which the individual capabilities of truck percentage in the left lane and total truck percentage were 35 percent and 28 percent, respectively.

The variance in the hourly mean truck speed, difference between hourly mean truck speed and the hourly mean car speed, and lane occupancy were positively correlated with the crash rates. The direction of the relationship between truck volume and the crash rates, however, did not show consistency.

The traffic analysis by Ishak et.al. in 2008 had reported that the rate of compliance with the truck lane restriction was lowest at night times (8 P.M. – 6 A.M.). The multiple regression analysis found that the crash rates increased with an increasing percentage of trucks in the left lane. However, it is not known whether the increase in the crash rate was due to the low compliance with the lane restriction or due to drunk drivers or fatigue at night times. Therefore the relationship between crash rate and the truck restrictions on the Atchafalaya Basin Bridge may be further investigated by adding variables into the regression equation that indicate day and night and also the alcohol
level of the driver(s) involved in the crashes. Also, it should be noted that continuous collection of traffic and crash data on the bridge may eliminate the need to make assumptions for the future investigations, and therefore help improve the accuracy of the results.
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VITA

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