

Organizational Results Research Report

October 2007
OR08.005

Investigating Large Truck- Passenger Vehicle Interactions

Prepared by University of
Missouri-Columbia and
Missouri Department
of Transportation

Investigating Large Truck-Passenger Vehicle Interactions

MoDOT Project RI 07-006

September 28, 2007

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TECHNICAL REPORT
STANDARD TITLE PAGE

1. Report No. FHWA MO-2007-00X		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle FINAL REPORT: Investigating Large Truck-Passenger Vehicle Interactions				5. Report Date September 2007	
				6. Performing Organization Code NA	
7. Author(s) Vap, Derek and Sun, Carlos				8. Performing Organization Report No. NA	
9. Performing Organization Name and Address University of Missouri E2509 Lafferre Hall Columbia, MO 65211				10. Work Unit No.	
				11. Contract or Grant No. Task Order MTI RI07-006	
12. Sponsoring Agency Name and Address Missouri Department of Transportation Federal Highway Administration 2271 St. Mary's Blvd. U.S. Department of Transportation Jefferson City, MO 65109 Washington, D.C.				13. Type of Report and Period Covered Final Report, March 20 – September 30, 2007	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract An analysis of truck-passenger car interactions was performed for Missouri urban and rural freeways. Trucks were found to travel 2 mph slower than other vehicles on urban interstates and 3.5 mph slower on rural interstates. These speed differences between trucks and passenger vehicles were not very large. Thus, there was no evidence that, on the average, trucks were traveling much faster than passenger cars. An implementation of differential speed limits could increase significantly the speed differences between trucks and passenger vehicles. In terms of lane usage, trucks concentrated mainly in the middle lanes and avoided the slow and fast lanes in situations with 5 and 6 lanes. The application of truck lane restrictions could alter the current truck lane usage significantly and increase the truck usage in the lane nearest the shoulder. In terms of number of crashes, trucks accounted for a smaller percentage of crashes as compared to passenger vehicles. However, an analysis of RSEC ratios showed that on urban freeways, the percentage of truck crashes is disproportionately larger when considering the volume or exposure of trucks. In contrast, the rural data in general shows that truck crashes are not as disproportional to the crash rates of passenger vehicles. These results point to a greater safety concern in truck-passenger vehicle interactions on urban freeways.					
17. Key Words Large Trucks, Passenger Cars, At-fault Crashes, Lane Usage, Speed Differential				18. Distribution Statement	
19. Security Classif (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No of Pages 35	22. Price

ABSTRACT

An analysis of truck-passenger car interactions was performed for Missouri urban and rural freeways. In an analysis of mean speeds, trucks were found to travel approximately 2 mph slower than other vehicles on urban interstates and 3.5 mph slower on rural interstates. These speed differences between trucks and passenger vehicles were not very large. Thus, there was no evidence that, on the average, trucks were traveling much faster than passenger cars. The result was statistically significant for rural but not for urban interstates. One reason for the lower speed differences in urban areas could be due to the higher traffic volumes and lower speeds. There was no significant difference in speed differentials between daytime and nighttime on rural freeways.

In terms of lane usage, trucks concentrated mainly in the middle lanes and avoided the right-most and left-most (median) lanes in situations with 5 and 6 lanes. With 3 lanes present, trucks tended to use the middle and right-most lanes. The 4-lane scenario seemed to be anomalous as trucks tended to travel in the two left-most lanes. The application of truck lane restrictions could alter the current truck lane usage significantly and increase the truck usage in the right-most lane.

In terms of number of crashes, trucks accounted for a smaller percentage of crashes as compared to passenger vehicles. In particular, trucks accounted for 19.9% and passenger vehicles for 68.2% of fatal crashes. However, an analysis of truck at-fault crash rates versus passenger vehicle at-fault crash rates, named RSEC ratios, showed that on urban freeways, the percentage of truck crashes is disproportionately larger when considering the volume or exposure of trucks. In contrast, the rural data in general shows that truck crashes are not as disproportional to the crash rates of passenger vehicles. These results point to a greater safety concern in truck-passenger vehicle interactions on urban freeways.

EXECUTIVE SUMMARY

The impact of trucks on the efficiency and safety of interstates is a highly debated topic in the field of transportation engineering. There have been different strategies proposed to improve truck-passenger vehicle interactions including differential speed limits, truck lane restrictions and even truck-only freeways. Missouri interstates have a relatively high volume of truck traffic which gives the Missouri Department of Transportation (MoDOT) a large stake in this area of research. The result of this research report is intended to provide MoDOT with information on truck operations and assist in policy decisions. Research was performed by studying speed differentials between large trucks and passenger vehicles, truck lane-usage on urban interstates, and at-fault percentages in fatal and injury interstate crashes involving at least one large truck and one passenger vehicle.

On urban interstates, **Table A** shows that trucks traveled slower than other vehicles by around 2.25 mph. This was observed in both Kansas City and St. Louis. The small difference in speeds was not found to be statistically significant even though it was observed consistently across multiple freeway segments. On rural interstates, **Table A** shows that trucks traveled on average 3.5 mph slower than other vehicles. The lower average truck speed was found to be statistically significant. A comparison was also made between rural daytime and nighttime (7 pm – 6 am) speeds for trucks. Trucks traveled slower than other vehicles an average of 3.50 mph during nighttime and 3.45 mph during daytime. This slight temporal speed difference between daytime and nighttime was not found to be statistically significant.

Table A - Summary of Urban Interstate Speed Differentials

Location	Posted Speed (mph)	Avg. TimeMS (mph)		Avg. Speed Diff. (mph)	Statistically Significant?
		Truck	Non-Truck		
KC	65,55	46.07	48.58	-2.51	No
STL	60	48.48	50.51	-2.03	No
Total Urban	65,60,55	47.27	49.55	-2.27	No
Rural I-70	70	70.03	73.55	-3.52	Yes

Truck lane usage was consistent with the intuition that the majority of trucks use the middle lane(s) when traveling on urban interstates to avoid the slow and fast lanes. However, in the anomalous four-lane situations, it was found that approximately 70% of trucks were traveling in the two fastest lanes. Results of lane-usage for each lane configuration are shown in **Table B**.

Table B - Truck Lane-Usage on Urban Interstates

No. of Lanes Present in Each Direction	No. of Trucks	Lane Usage (# of Vehicles and %)											
		Fastest Lane ←-----→ Slowest Lane											
		Lane 1		Lane 2		Lane 3		Lane 4		Lane 5		Lane 6	
3 Ln.	1215	192	15.8%	557	45.8%	466	38.4%						
4 Ln.	220	68	30.9%	88	40.0%	40	18.2%	24	10.9%				
5 Ln.	874	65	7.4%	235	26.9%	304	34.8%	177	20.3%	93	10.6%		
6 Ln.	102	8	7.8%	17	16.7%	21	20.6%	7	6.9%	30	29.4%	19	18.6%

Truck At-fault Percentages on Interstate Crashes

Table C shows an analysis of all fatal, disabling injury, and minor injury crashes involving truck and/or passenger vehicles on Missouri interstates between 2002 and 2006. It was found that passenger vehicles were solely at fault in 68.2% of fatal crashes, 59.8% of disabling injury crashes, and 44.3% of minor injury crashes while trucks were solely at fault 19.9%, 29.5%, and 41.0% of the time in fatal, disabling injury, and minor injury crashes, respectively. Table C shows that trucks are involved in a smaller percentage of crashes as compared to passenger vehicles if exposure is not taken into account by using truck and vehicle volumes. This is more true in the case of fatal crashes (19.9% vs. 68.2%) and less true in the case of minor injury crashes (41.0% v. 44.3%).

Table C - Vehicle At-fault Percentages in Fatal Truck-Passenger Vehicle Crashes

Veh. At Fault	No. of Crashes and % of Total		
	Fatal Crashes	Disabling Injury	Minor Injury
Pass. Veh. Only	103 (68.2%)	288 (59.8%)	907 (44.3%)
Truck Only	30 (19.9%)	142 (29.5%)	839 (41.0%)
Both Veh.	13 (8.6%)	34 (7.1%)	158 (7.7%)
None	5 (3.3%)	18 (3.7%)	143 (7.0%)
Total Sample	151 (100%)	482 (100%)	2047 (100%)

In contrast to **Table C**, **Table D** takes into account exposure in analyzing crashes. In other words, **Table D** takes into account the percentage of trucks in the total traffic stream. Thus the data in **Table D** shows if truck at-fault in crashes are “over or under represented” as compared to non-truck at-fault in crashes. This data is expressed as at-fault section crash rate (RSEC) ratios. The numerator in the ratio is the truck at-fault crash rate and the denominator is the passenger vehicle at-fault crash rate. If this ratio is greater than 1, then truck crashes are over represented when volume (exposure) is taken into account. If this ratio is less than 1, then passenger vehicle crashes are over represented. **Table D** shows that on urban freeways, RSEC ratios for trucks are consistently over 1 especially for minor injury crashes (e.g. 4.928, I-70; 3.345, I-44). Similarly, RSEC ratios are rarely under 1. One exception when comparing trucks to passenger cars is the case of fatal crashes on rural I-70 where the RSEC ratio is 0.46, i.e. passenger car at-fault crash rate is more than two times larger than truck at-fault crash rate. In general, **Table D** shows the difference between truck and passenger vehicle at-fault crash rates are statistically significant for minor injury crashes probably due to the larger sample size. One caution in interpreting the statistical significance is that the sample size is not very large, especially for fatal crashes. For RSEC ratios on urban freeways, **Table D** shows an interesting trend upward as the severity type decreases.

Table D – RSEC Ratios vs. At-fault Crash Rate Statistical Significance

Interstate Location		RSEC Ratio vs. At Fault Crash Rate Significance					
		Fatal		Disabling Injury		Minor Injury	
		RSEC Ratio	At Fault Crash Rate Significant?	RSEC Ratio	At Fault Crash Rate Significant?	RSEC Ratio	At Fault Crash Rate Significant?
I-70	Rural	0.46	Yes	1.294	No	1.71	No
	Urban	1.771	No	2.28	No	4.928	Yes
I-44	Rural	0.602	No	0.822	No	2.524	Yes
	Urban	1.235	No	1.755	No	3.345	Yes
I-270	Urban	1.922	No	6.15	No	6.667	Yes
I-435	Urban			2.307	No	12.459	Yes

*The I-435 Urban scenario had a low frequency of fatal crashes and was not included in the analysis of at-fault crash rates.

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INTRODUCTION AND BACKGROUND INFORMATION

Due to concerns expressed by its motorists, the Missouri Department of Transportation (MoDOT) has articulated the importance of research regarding large truck travel and its effect on the safety of its highways. Missouri has anywhere from 5% trucks on urban interstates to almost 40% trucks on its rural interstates. With these numbers on the rise each year, increasing truck safety is a key objective in the improvement of the statewide transportation network. Measures to be used in determining the safety of interactions between large trucks and passenger autos are speed differentials between the vehicle types (in both rural and urban settings), truck lane usage on sections of urban interstates with three or more lanes per direction, and at-fault percentages in fatal and injury truck-passenger vehicle crashes.

The issue of increased truck travel has raised much debate over policies of truck speed limits, restricted truck lanes, and dedicated truck-only lanes. Although an exhaustive literature review was not necessary for this report, important sources on the topic are provided at the end of the report. Literature shows differing opinions on the effects of differential speed limits (DSL). Research has found that states with a uniform speed limit (USL) compared to states with DSL do not show many differences in mean and 85th % speeds of trucks (Harkey & Mera, 1994). Harkey & Mera also found that states with a USL had higher car into truck and truck into car crashes than states with a DSL. A study has also shown that the two types of speed limits do not produce any differences in crash rates (Garber & Gadiraju, 1991). Research has also shown that high speed differentials between trucks and passenger vehicles increase the severity of crashes (Council et. al., 2004).

The effects of truck lane restrictions on lane usage and traffic flow on freeways were modeled by Cate and Urbanik (2004) using the VISSIM simulation model. The authors found that the implementation of truck lane restrictions in a variety of scenarios is shown to have little effect on a number of traditional measures, including average speed, speed differential between cars and large trucks, and level of service. Lane restrictions were found to change speed differentials by less than one mph in most situations. However, when grades increase speed differentials continue to increase by as much as 10 mph between large trucks and passenger cars. This may seem to decrease safety due to the higher possibility of rear-end crashes, but lane restrictions produce lower frequencies of lane changes which has been shown to reduce conflicts and increase safety. The ultimate results showed that the practice of prohibiting trucks in the leftmost lane when there are three or more lanes of travel in a single direction has no negative effect on traffic safety or efficiency.

Interactions between large trucks and passenger cars are important topics for research since they represent more than 60% of all fatal truck crashes and because the passenger car occupant is much more likely to be killed according to Council et. al. (2003). Blower's (Blower, 1998) primary approach was to analyze driver-related factors in light of how the crash occurred using the trucks involved in fatal accidents (TIFA) files for fatal crashes, and NHTSA's National Automotive Sampling System General Estimates System (NASS-GES) for nonfatal crashes. Using the coding of driver-related contributing factors which contribute to the crash recorded by FARS analysts together with relative movement and position of the vehicles before the crash,

one or both drivers were assigned fault in the crash. The TIFA analysis showed the passenger vehicle driver to be three times more likely to be a contributor to the crash. Stuster (1999) developed a set of 26 unsafe driving acts (UDA's) of passenger vehicle drivers in truck-car crashes. The UDA's were identified by police crash investigators and truck drivers. This research only analyzed the fault of the passenger vehicle driver which gives the preconceived notion that passenger vehicle drivers are mostly at fault. There is a lack of input on the behaviors of truck drivers who are at fault.

An analysis of the space and time mean speeds on urban interstates in Kansas City and St. Louis between large trucks and passenger cars will be used to confirm or dispute the notion that trucks travel much faster than other vehicles on urban interstates. The same task was performed for Missouri rural interstates using time mean speeds. Research was also performed to provide more information about the lane usage of trucks on urban interstates in Kansas City and St. Louis. Lastly, comprehensive research was conducted into the causal factors and at-fault percentages of truck-passenger vehicle fatal and injury crashes.

DATA COLLECTION

Previous data collected by researchers in the University of Missouri-Columbia's civil engineering department were utilized in the urban speed differential analyses while MoDOT permanent count station number 500 located on I-70 just east of Boonville, Missouri, provided speed data for the rural interstate scenario. The available urban data was collected using Portable Overhead Surveillance Trailers (POSTs) and analyzed with ReID vehicle reidentification/tracking software. Significant data was available for sections of roadway in St. Louis (I-70, I-270) and Kansas City (I-70, I-435). The time segments include AM and PM peak periods as well as non-peak periods. These data were collected for previous MoDOT and NCHRP studies in 2002 and 2003. The rural speed data set is six 24-hour periods from Tuesday March 20, 2007 to Thursday March 22, 2007 and Tuesday March 27, 2007 to Thursday March 29, 2007. It should be noted that the data collected from I-435 in Kansas City is located just across the state line in Kansas. Although this segment of the interstate is not technically located in Missouri, the traffic is very similar in both states along I-435 due to the frequent travel across state lines in Kansas City.

The same data sets used for determining urban speed differentials was used in the analysis of truck lane-usage. Digital video was analyzed by researchers and the lane in which trucks were traveling was tabulated. Data segments consisted of approximately five minute samples during morning and evening peak and off-peak periods on interstates with three, four, five, and six lanes. A total of 2411 large trucks were visually identified.

The data for determining the at-fault percentages in fatal and injury truck-passenger vehicle crashes was gathered and tabulated from the MoDOT Transportation Management System (TMS) database for fatal and injury crashes involving large trucks. The five-year data set includes all truck-involved fatal crashes that occurred on a Missouri interstate from 2002-2006. Excluding for crashes at interchanges and those not involving a combination of at least one large truck and one passenger vehicle, a sample of 151 fatal crashes was analyzed. The injury crashes were split by severity into disabling injury and minor injury. The disabling injury crash sample was 482 truck-passenger vehicle crashes while the minor injury sample was 2,087 crashes.

METHODOLOGY

In traffic engineering, the use of space mean speed (SMS) is often preferred to time mean speed (TimeMS) since SMS gives a better assessment of the travel over long distances. TimeMS is often used as a surrogate for SMS since SMS is more difficult to obtain. One of the most common methods for obtaining SMS is the use of the average/floating car study. Another method for obtaining SMS is the video reidentification method (ReID) which is video tracking of vehicles from point to point along a freeway. This is the method used in this research for deriving SMS on urban interstates. These speeds were already available since such data was collected for previous MoDOT and NCHRP studies. Since SMS was not available for rural interstates, TimeMS from loop detector stations was used as a surrogate. However, concerns were voiced about using SMS in the urban area and TimeMS in the rural area. Therefore, SMS was converted to TimeMS using the following equation: $TimeMS = SMS + \frac{\sigma_{SMS}^2}{SMS}$

The vehicles that were detected by ReID were then sorted into two categories by vehicle classification. Vehicles were classified as either a large truck or a passenger vehicle. Vehicles listed in the Missouri Uniform Accident Report (MUAR) form by body type numbers 20-26 are considered large trucks, and all other body types, excluding bus body types 6-9, are considered passenger vehicles. For the remainder of the report, any vehicle referred to as a large truck/commercial vehicle or a passenger vehicle are consistent with these classifications. For each urban data segment SMS were calculated for large trucks and for passenger vehicles, and a speed differential was calculated by subtracting the passenger vehicle SMS from the large truck SMS. Average speeds and differentials were computed for interstate segments I-70 and I-435 in Kansas City and I-70 and I-270 in St. Louis.

The rural speed data acquired from MoDOT's permanent count station 500 was available from 60-80 mph in 2 mph bins by hour for trucks and for all vehicles. The data contained truck volumes, total volumes, and truck and total volume speeds for the specified bins. With this information, weighted truck speeds and car volumes could be calculated which in turn allowed for the derivation and calculation of weighted car speeds. Therefore, speed differentials between large trucks and passenger vehicles were determined in a rural setting. The differentials were averaged for 24-hour periods and for the whole data set, and a two sample statistical t-test assuming unequal variances was performed. Speed differentials were also compared temporally between night and day. The nighttime period was from 7 pm to 6 am while the daytime period was from 6 am to 7 pm. The 7 pm and 6 am cutoffs for night and day were chosen by inspection of a clearly visible drop or rise in vehicle volume.

Digital video data collected by the POST systems on urban interstates in Kansas City and St. Louis was visually inspected for approximately five minute periods. The lane usage of large trucks was identified from the video. A lane numbering convention from median, or fastest, lane to shoulder, or slowest, lane was used. For example, on a three lane interstate the median lane is numbered with a 1, the middle lane is 2, and the shoulder lane is number 3. Interstates with four, five, or six lanes in one direction were numbered in a similar fashion. After the truck

lane-usage was tabulated, observations were totaled and a percentage of lanes used for each lane scenario were calculated.

The MoDOT Transportation Management System database was queried for all fatal, disabling injury, and minor injury crashes on a Missouri interstate from 2002-2006 in order to perform an analysis of crashes involving both trucks and passenger vehicles. Through code written in Matlab version 6.5 (see **Appendix**) the crashes were filtered to exclude records located at interchanges so as not to introduce other factors of causality and to determine the effects of truck-passenger vehicle interaction on main line interstates.

Crashes not involving at least one large truck and one passenger vehicle were also filtered out in this process. To determine which vehicle was at fault, a driver that is coded with a probable contributing circumstance in the crash report will be categorized at fault. Specifically, if any one or more of the codes 1-21 in the “Probable Contributing Circumstances” section of the Missouri Uniform Accident Report (MUAR) were reported, a driver was considered at fault. Lastly, crashes were classified as ‘passenger vehicle only’ at fault, ‘truck only’ at fault, ‘both’ at fault, or ‘none’ at fault. Then a percentage was calculated for each at-fault class by dividing by total number of crashes for that segment. Overall at-fault percentages of fatal, disabling injury, and minor injury crashes were descriptive of truck-passenger vehicle interactions, but more analysis was done to determine the significance of an at-fault percentage by further filtering the crashes for rural and urban interstates and then compared to the percentage of volume represented by the vehicle type in question over the same segment.

In order to more effectively quantify the at-fault percentage, the percentages were calculated by segments for four major interstates in Missouri according to urban/rural classification. Interstates 70, 44, 270, and 435 were used for the analysis since they constitute the majority portion of Missouri freeways, and these interstates represent approximately 80% of fatal, 75% of disabling injury, and 71% of minor injury truck-passenger vehicle crashes. Each interstate was divided into rural and urban segments per MoDOT specifications and the at-fault percentage was calculated as described in the paragraph above. For example, I-70 EB is urban from log mile 0 to 23.124 and from 101.118 to 106.375, etc. Once the at-fault classification was assigned for both directions of the interstate, the crashes were totaled for the respective rural/urban classification and divided by the total number of crashes over those segments to attain the at-fault percentage. These segment percentages are more detailed representations of the 'overall' at-fault percentages for all Missouri interstates and can be compared to the respective volumes over the same segments in order to determine the significance of at-fault.

Over the same rural and urban segments that at-fault percentage was calculated, a truck percentage and passenger vehicle percentage of AADT was computed. Over these rural/urban segments, MoDOT has either actual or estimated volumes for smaller segments, ranging from 0.02 miles to 15.5 miles. For each segment, average commercial vehicle and AADT volumes for the five-year span (2002-2006) were calculated. Then this average was weighted by the distance it was measured over. Next, for each rural or urban segment the average weighted volume over that segment was calculated and divided by its segment length. This gives the five-year average volumes over that particular segment. Lastly, truck and passenger vehicle percentages of AADT were computed over the whole rural or urban Interstate.

For a freeway section, **Equation 1** was used to calculate an at-fault crash rate for both trucks and passenger vehicles. The at-fault crash rates were computed to more accurately explain the significance of the at-fault percentages. The crashes that were evaluated for the 5-year study period were further broken down by yearly crashes to attain a significant sample to perform a t-test. In layperson's terms a t-test is a way of determining whether differences in means were random versus systematic. A t-test is a test of the null hypothesis that the means of two normally distributed populations are equal. The significance level of a t-test, defined by the Greek letter alpha (α), determines the value of the t-statistic that will yield the probability of a t value being greater than the computed value. If the probability of the t value is less than the significance level, the difference of means is said to be statistically significant. The results from the yearly at-fault t-test is then used to support the at-fault crash rate ratio in determining whether crashes are over represented by one vehicle class.

Equation 1: At-fault crash rate for a section

- $RSEC_{AF} = \frac{100,000,000 \times C_{AF}}{365 \times T \times V \times L}$, where
 $RSEC_{AF}$ = At-fault crash rate for a section
 C_{AF} = # of at-fault crashes
T = time frame of analysis, years
V = AADT
L = length of the section

Now that at-fault crash rates for both trucks and passenger vehicles have been determined for each interstate, the at-fault crash rate ratios (RSEC ratio) can be derived using **Equation 2**. When dividing the truck crash rate by the passenger crash rate the constants cancel out because the two rates are compared over the same time and section length; therefore, the RSEC ratio is simply a function of the number of at fault crashes and volumes. So if this ratio is greater than 1, then it means that the truck crashes are over represented when volume or exposure is taken into account. And if this ratio is less than 1, then it means that the passenger vehicle crashes are over represented.

Equation 2: At-fault crash rate ratio

- $RSECRatio = \frac{T_C P_V}{T_V P_C}$, where
RSECRatio = At-fault crash rate ratio
 T_C / P_C = Truck/Passenger, vehicle # of at-fault crashes
 T_V / P_V = Truck/Passenger, vehicle volume

ANALYSIS AND RESULTS

Speed Differentials

An analysis of the speed differentials on urban interstates disproves the notion that large trucks travel at much higher speeds than passenger vehicles. The columns of **Table 1** show the average space mean truck speeds, non-truck speeds, average speed differentials, t-statistic, significance level, number of trucks, percent of trucks, number of non-trucks, percent of non-trucks, and total number of vehicles. The rows show data from Kansas City and St. Louis, and for I-70, I-435, and I-270. As can be seen in **Table 1**, large trucks travel 2.1 mph slower than passenger vehicles on average. There were a few observations where a large truck traveled at higher speeds, but these observations were a small proportion of the total vehicles.

Table 1 – Urban Interstate Space Mean Speed Differentials

Location	Avg. SMS (mph)		Avg. SMS Diff. (mph)	Stat. Significance		Sample Size				
	Truck	Non-Truck		t-statistic	P(T<=t) one-tail	Truck		Non-Truck		Total
						# of Veh.	% of Total	# of Veh.	% of Total	# of Veh.
KC	45.92	48.20	-2.28	-0.79	0.22	393	8.99%	3978	91.01%	4371
I-70	46.40	48.46	-2.06	-0.51	0.31	180	9.24%	1768	90.76%	1948
I-435	45.36	47.89	-2.53	-0.60	0.28	213	8.79%	2210	91.21%	2423
STL	48.22	50.15	-1.93	-0.48	0.32	264	6.74%	3652	93.26%	3916
I-70	49.24	50.99	-1.75	-0.27	0.39	142	10.86%	1166	89.14%	1308
I-270	47.45	49.51	-2.06	-0.39	0.35	122	4.68%	2486	95.32%	2608
I-70 All	47.82	49.73	-1.91	-0.39	0.35	322	9.89%	2934	90.11%	3256
Overall	47.07	49.18	-2.10	-0.64	0.27	715	8.63%	7630	92.07%	8287

A total of 715 trucks comprising 8.63% of the ReID vehicles were analyzed. These numbers offer a significant sample of the population and can be expected to represent the travel on urban interstates during morning and evening peak and off-peak periods. In all urban setting scenarios a t-test showed that no significant difference in speeds was present.

Questions were raised about comparing space mean speeds in an urban setting to time mean speeds in a rural setting. Therefore, time mean speeds were calculated from the space mean speeds and are presented in **Table 2**. This conversion to time mean speed increased the average differential between truck and non-truck speeds slightly to 2.27 mph due to the fact that time mean speed is a larger estimate of speed than space mean speed. In turn, this increases the overall average of the faster traveling vehicles (non-truck) by a greater margin than it does the truck speeds. However, time mean speed differentials, like the space mean speed, did not show any statistical significance between truck and non-truck speed differentials when using the t-test.

Table 2 – Urban Interstate Time Mean Speed Differentials

Location	Avg. TimeMS (mph)		Avg. TimeMS Diff. (mph)	Stat. Significance		Sample Size				
	Truck	Non-Truck		t-statistic	P(T<=t) one-tail	Truck		Non-Truck		Total
						# of Veh.	% of Total	# of Veh.	% of Total	# of Veh.
KC	46.07	48.58	-2.51	-0.87	0.19	393	8.99%	3978	91.01%	4371
I-70	46.53	48.66	-2.13	-0.53	0.30	180	9.24%	1768	90.76%	1948
I-435	45.54	48.49	-2.95	-0.70	0.24	213	8.79%	2210	91.21%	2423
STL	48.48	50.51	-2.03	-0.50	0.31	264	6.74%	3652	93.26%	3916
I-70	49.59	51.47	-1.88	-0.29	0.39	142	10.86%	1166	89.14%	1308
I-270	47.63	49.77	-2.14	-0.40	0.35	122	4.68%	2486	95.32%	2608
I-70 All	48.06	50.06	-2.01	-0.41	0.34	322	9.89%	2934	90.11%	3256
Overall	47.27	49.55	-2.27	-0.69	0.25	715	8.63%	7630	92.07%	8287

Another measure to look at when determining the safety of highways is the 85th percentile and 95th percentile speeds. **Table 3** shows that the 85th percentile speed for all urban interstates analyzed was 61.4 mph for trucks and 65.1 mph for passenger vehicles. The 95th percentile speed for trucks was 64.8 mph and 69.5 mph for passenger vehicles. Many DOTs often post speed limits based on the 85th percentile speed. It should be noted that all 85th percentile speeds are at or below two mph above the highest posted speed limit on the urban interstates analyzed, which was 65 mph. This may indicate that the majority of motorists are traveling near the posted speed limits; however, the 85th percentile speeds may be skewed a little low due to the fact that more of the data sets were taken during peak hours than during off-peak hours when congestion is less and vehicles travel at faster speeds. If true, the latter suggests that motorists travel at higher speeds during periods of low or non-existent congestion. The 95th percentile speeds also show this trend at as much as six mph above the highest posted speed limit. Another interesting observation is the speed differential between trucks and passenger vehicles increases as the speeds increase. Excessive speeding is a common factor, and although not specifically analyzed in this research, a portion of crashes involving trucks and passenger vehicles could be attributed to the larger speed differentials of the top 15% vehicles.

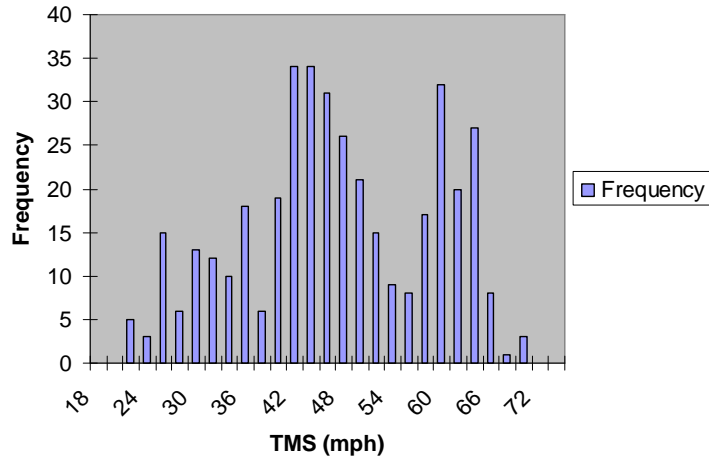
Table 3 – Urban Interstate 85th % and 95th % Speeds

Location	85th % Speed (mph)		95th % Speed (mph)	
	Truck TimeMS	Pass. Veh. TimeMS	Truck TimeMS	Pass. Veh. TimeMS
KC	60.124	64.898	63.118	69.265
KC I-70	60.681	63.167	63.100	66.825
KC I-435	59.148	66.412	62.362	71.121
STL	62.782	65.131	67.565	70.087
STL I-70	64.464	66.728	68.690	71.074
STL I-270	60.768	64.134	63.341	69.219
All Urban	61.409	65.062	64.778	69.542

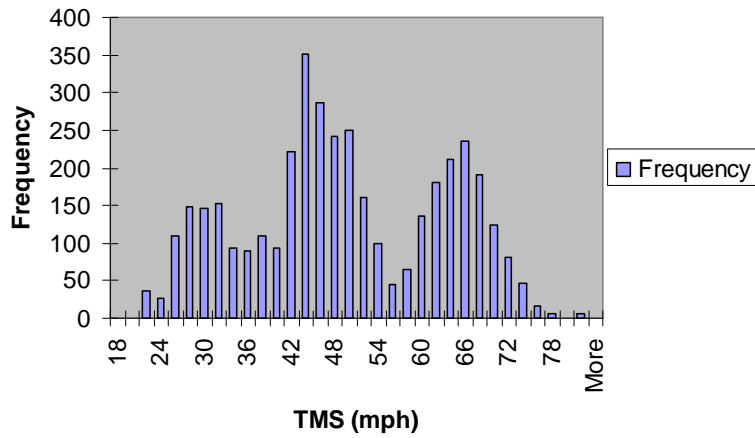
In order to apply statistical tests, it is important to examine a histogram of speeds to determine the normality of the distribution of vehicle speeds. The following histograms (**Figure 1**) show

the TimeMS of trucks and passenger cars in both Kansas City and St. Louis. Speeds in Kansas City look relatively normally distributed, while showing multiple modes due to the peak or off-peak periods of data collection. Similarly, vehicle speeds in St. Louis are fairly normally distributed, but with less cut-offs between periods of congestion and non-congestion.

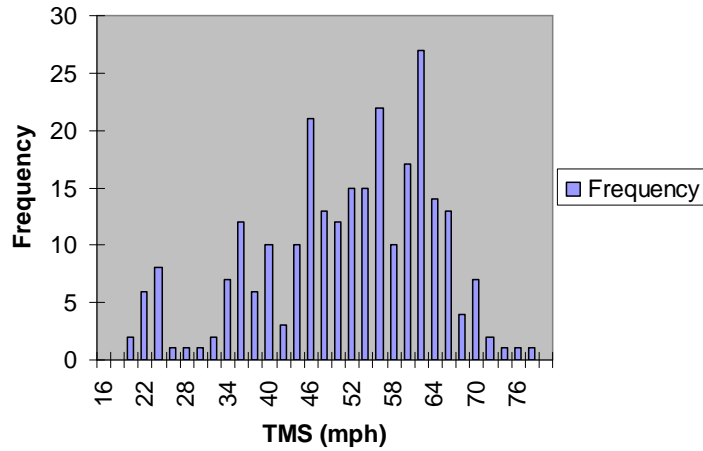
Histogram of KC Truck TimeMS



Histogram of KC Pass. Veh. TimeMS



Histogram of STL Truck TimeMS



Histogram of STL Pass. Veh. TimeMS

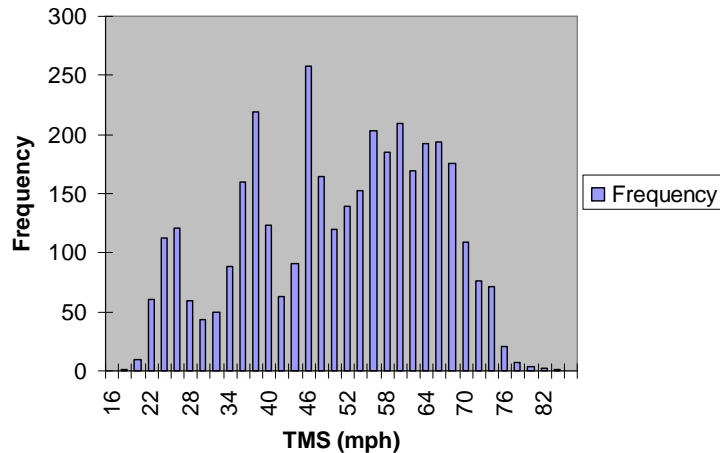


Figure 1 - Histogram of Urban Speeds

The rural interstate speed data support the findings in the urban setting that trucks travel slower, on average, than passenger vehicles. **Table 4** columns show the time mean truck speed, passenger vehicle speed, speed difference, t-statistic, and significance level. **Table 4** shows trucks speeds of 70.03 mph as compared to passenger vehicles of 73.55 mph, for a difference of -3.52 mph. An appropriate two-sample t-test assuming equal or unequal variances was performed on each 24-hour period and all speed differentials proved to be statistically significant. This is significant because as the speed gap grows between large trucks and passenger vehicles, the safety of the roadway could decrease.

Table 4 – Rural Interstate Time Mean Speed Differentials

Sample Period	24-hr Average TimeMS (mph)			Stat. Significance	
	Truck	Pass. Veh.	Difference	t-Statistic	P(T<=t) one-tail
3/20/2007	70.23	73.55	-3.32	-18.10	2.06E-13
3/21/2007	70.12	73.61	-3.49	-21.66	2.58E-16
3/22/2007	70.24	73.72	-3.48	-15.60	3.42E-12
3/27/2007	69.23	73.03	-3.80	-11.90	6.33E-07
3/28/2007	70.43	73.89	-3.47	-21.26	2.58E-15
3/29/2007	69.93	73.52	-3.59	-17.51	2.33E-11
Total	70.03	73.55	-3.52	-17.67	1.05E-07

Speeds were also analyzed to determine if there is a significant speed differential between night and day. Due to the prevalence of truck travel at night on rural interstates, it is of interest to compare the night segment, 7 pm to 6 am, and day segment, 6 am to 7 pm. These time periods were chosen by the researchers and MoDOT staff given the changes in overall volumes. It can be seen from **Table 5** that there was no statistical significance in the speed differentials between day and night.

Table 5 – Rural Interstate Temporal Speed Differentials

Sample Period	Avg. Temporal Speed Diff. (mph)			Stat. Significance	
	Night (7pm-6am)	Day (6am-7pm)	Difference	t-Statistic	P(T<=t) one-tail
3/20/2007	-3.53	-3.38	-0.15	-0.18	0.24
3/21/2007	-3.39	-3.47	0.08	0.11	0.25
3/22/2007	-3.56	-3.33	-0.23	-0.36	0.22
3/27/2007	-3.56	-3.42	-0.14	-0.06	0.23
3/28/2007	-3.42	-3.44	0.02	0.07	0.29
3/29/2007	-3.52	-3.63	0.12	0.41	0.16
Total	-3.50	-3.45	-0.05	1.98E-04	0.23

Similar to speeds in an urban setting, it is important to look at the 85th percentile and 95th percentile speeds on the rural interstate. **Table 6** shows that the 85th percentile speed for trucks is 74 mph and 77.5 mph for passenger vehicles. The 95th percentile speeds for trucks and passenger vehicles are 76.6 mph and 80+ mph, respectively. Speeds above 80 mph are not specifically calculated due to data restraints but this would be of particular interest to further research the actual speeds of those traveling faster than 80 mph. If the faster or median lanes, lanes 1 & 3, were looked at and the shoulder lanes discarded, the truck 85th percentile speed would be almost 77 mph and the passenger vehicle 85th percentile speed would be approximately 79 mph or more. The large differential between trucks and passenger vehicles in the faster lanes and those in the slower lanes potentially create an increased opportunity for crashes. The larger the speed differential between vehicles traveling in the same lane encourages more lane changes, more interaction between the vastly different capabilities of the two classes of vehicles and thus,

more chances for a crash. Imposing truck or differential speed limits on an interstate with only two lanes per direction like I-70, where the differential between passenger vehicles and trucks is already significant, could increase this speed differential and therefore increase the opportunity for crashes.

Table 6 – Rural Interstate 85th % and 95th % Speeds

I-70 Location	85 th % Speed (mph)		95 th % Speed (mph)	
	Trucks	Pass. Veh.	Trucks	Pass. Veh.
EB left (median) lane	75.3	77.0	77.8	80+
EB right lane	71.3	76.7	74.5	79.8
EB both lanes	73.3	76.8	76.2	80+
WB left (median) lane	78.2	80+	80+	80+
WB right lane	71.0	76.2	74.0	79.8
WB both lanes	74.6	78.1	77.0	80+
I-70 Overall	74.0	77.5	76.6	80+

The following two histograms depict the distributions of truck and passenger vehicle speeds on rural I-70. The distributions are clearly divided into two bell shaped curves representing the distribution of speeds between the slower and faster lanes.

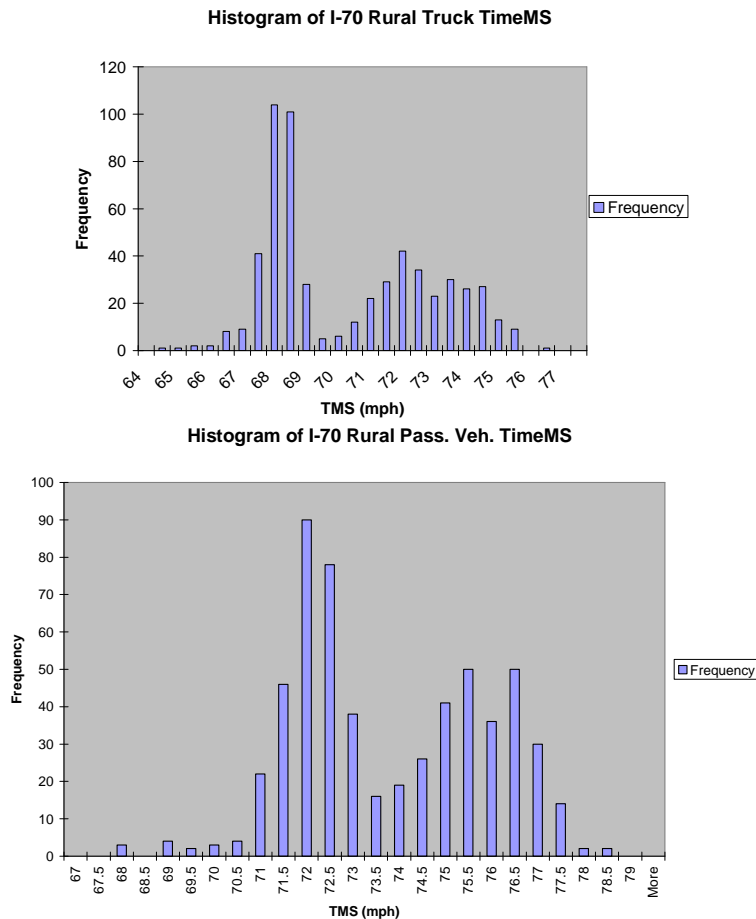


Figure 2 - Histogram of Rural Speeds

Lane Usage

Lane usage in an urban setting may reveal safety issues, because if trucks traveling through a corridor are using the slower shoulder lanes, this may cause more conflicts between entering and exiting vehicles. Similarly, if trucks are traveling primarily in the faster or median lanes, this may slow the upstream traffic, which in turn could decrease capacity and safety by causing other vehicles to perform more lane changes. The lane-use results in **Table 7** primarily follow one's intuition that large trucks attempt to travel in the middle lanes in urban areas. However, when there are four lanes per direction present on the interstate, trucks were observed traveling in the two fastest lanes. This could be due to specific situations pertaining to the freeway segments that affect the results. For example, the proximity of the freeway segment to major interchanges might affect the truck lane usage patterns. The 4-lane per direction scenario in Kansas City was collected upstream of a split of the interstate where the median lanes continued into the downtown area. This may explain the shifted lane usage results.

Table 7 – Truck Lane-Usage

No. of Lanes Present	No. of Trucks	Lane Usage (# of Vehicles and %)											
		Fastest Lane ←-----→ Slowest Lane											
		Lane 1		Lane 2		Lane 3		Lane 4		Lane 5		Lane 6	
3 Ln.	1215	192	15.8%	557	45.8%	466	38.4%						
4 Ln.	220	68	30.9%	88	40.0%	40	18.2%	24	10.9%				
5 Ln.	874	65	7.4%	235	26.9%	304	34.8%	177	20.3%	93	10.6%		
6 Ln.	102	8	7.8%	17	16.7%	21	20.6%	7	6.9%	30	29.4%	19	18.6%

A topic particularly relating to lane usage is the concept of restricting trucks to the one or two lanes closest to the shoulder in an attempt to restrict interaction with faster traveling passenger vehicles. It should be noted that in most observed situations on urban interstates in Missouri, restricting trucks to the farthest right-hand lanes would encourage these vehicles to the lanes where most weaving on and off the interstate occurs. Lane restrictions should be considered on a case-by-case basis after a study of lane usage is performed; the practice may be useful when truck traffic is more heavily intra-city based than inter-city based.

At-fault Percentages

In a sample of 151 total truck-passenger vehicle fatal crashes on all Missouri interstates from 2002 to 2006, nearly 20% were assigned fault exclusively to the truck as shown in **Table 8**. Approximately 68% of the crashes were caused solely by passenger vehicles. When traffic volumes on the interstate are considered, the proportion of crashes caused by trucks to their corresponding volumes may not appear to be proportional. Depending on the location on Missouri interstates, trucks being at-fault in almost 20% of the fatal crashes may appear disproportionate when considering truck volumes. Further analysis conducted into at-fault percentages of crashes to volume in urban and rural areas will be discussed. Additionally, disabling injury and minor injury crashes may point to the aforementioned disproportionate amount of trucks causing crashes. **Table 8** shows that trucks are solely at fault 29.5% of the time in disabling injury truck-passenger vehicle crashes, and 41% of minor injury crashes. This is an

interesting trend upward as the severity type decreases which may be explained by the misperceptions that passenger vehicle drivers have about the capabilities of large trucks, resulting in more serious crashes caused by passenger vehicles.

Table 8 – Vehicle At-fault Percentages in Truck-Passenger Vehicle Crashes

No. of Crashes and % of Total			
Veh. At fault	Fatal Crashes	Disabling Injury	Minor Injury
Pass. Veh. Only	103 (68.2%)	288 (59.8%)	907 (44.3%)
Truck Only	30 (19.9%)	142 (29.5%)	839 (41.0%)
Both Veh.	13 (8.6%)	34 (7.1%)	158 (7.7%)
None	5 (3.3%)	18 (3.7%)	143 (7.0%)
Total Sample	151 (100%)	482 (100%)	2047 (100%)

The first step in determining whether the at-fault percentages are overrepresented by one vehicle or another is to distinguish between urban and rural crashes so that they may be compared to appropriate volumes. All truck-passenger vehicle crashes from 2002-2006 on I-70, I-44, I-270, and I-435 were split by urban or rural classification of roadway and tabulated as seen in **Table 9**. These four interstates were used as they represent a good portion of all interstate truck-passenger vehicle crashes: approximately 80% of fatal crashes, 75% of disabling injury crashes, and 70% of minor injury crashes involving truck-car interaction on interstates occur on these four routes. It can be seen that trucks cause approximately 7% more fatal crashes in urban areas than in rural areas. Passenger vehicles cause approximately 2.5% more fatal crashes on urban interstates than on rural ones. Disabling and minor injury crash at-fault percentages are fairly consistent for both trucks and passenger vehicles between rural and urban. More detailed at-fault percentages are shown in **Tables 10, 11, and 12**.

Table 9 – Selected Interstate At-Fault Percentages by Classification

Veh. At Fault	I-70, I-44, I-270, I-435: No. of Crashes and % of Total					
	Fatality		Disabling Injury		Minor Injury	
	Rural	Urban	Rural	Urban	Rural	Urban
Pass. Veh. Only	48 (67.6%)	35 (70.0%)	104 (62.3%)	117 (60.3%)	162 (45.0%)	477 (43.9%)
Truck Only	12 (16.9%)	12 (24.0%)	48 (28.7%)	57 (29.4%)	156 (43.3%)	443 (40.8%)
Both Veh.	6 (8.5%)	3 (6.0%)	11 (6.6%)	11 (5.7%)	27 (7.5%)	84 (7.7%)
None	5 (7.0%)	0 (0%)	4 (2.4%)	9 (4.6%)	15 (4.2%)	83 (7.6%)
Total Sample	71 (100%)	50 (100%)	167 (100%)	194 (100%)	360 (100%)	1087 (100%)

Table 10 – Fatal At-Fault Percentages by Classification

Veh. At Fault	No. of Fatal Crashes and % of Total					
	I-70		I-44		I-270	I-435
	Rural	Urban	Rural	Urban	Urban	Urban
Pass. Veh. Only	22 (64.7%)	13 (76.5%)	26 (70.3%)	18 (72.0%)	4 (57.1%)	0 (0%)
Truck Only	5 (14.7%)	4 (23.5%)	7 (18.9%)	6 (24.0%)	1 (14.3%)	1 (100%)
Both Veh.	3 (8.8%)	0 (0%)	3 (8.1%)	1 (4.0%)	2 (28.6%)	0 (0%)
None	4 (11.8%)	0 (0%)	1 (2.7%)	0 (0%)	0 (0%)	0 (0%)
Total Sample	34 (100%)	17 (100%)	37 (100%)	25 (100%)	7 (100%)	1 (100%)

Table 11 – Disabling Injury At-Fault Percentages by Classification

Veh. At Fault	No. of Disabling Injury Crashes and % of Total					
	I-70		I-44		I-270	I-435
	Rural	Urban	Rural	Urban	Urban	Urban
Pass. Veh. Only	36 (53.7%)	53 (61.6%)	68 (68.0%)	38 (63.3%)	20 (51.3%)	6 (66.7%)
Truck Only	23 (34.3%)	21 (24.4%)	25 (25.0%)	18 (30.0%)	16 (41.0%)	2 (22.2%)
Both Veh.	6 (9.0%)	7 (8.1%)	5 (5.0%)	3 (5.0%)	1 (2.6%)	0 (0%)
None	2 (3.0%)	5 (5.8%)	2 (2.0%)	1 (1.7%)	2 (5.1%)	1 (11.1%)
Total Sample	67 (100%)	86 (100%)	100 (100%)	60 (100%)	39 (100%)	9 (100%)

Table 12 – Minor Injury At-Fault Percentages by Classification

Veh. At Fault	No. of Minor Injury Crashes and % of Total					
	I-70		I-44		I-270	I-435
	Rural	Urban	Rural	Urban	Urban	Urban
Pass. Veh. Only	90 (47.1%)	216 (45.8%)	70 (42.2%)	103 (45.2%)	128 (45.7%)	30 (28.0%)
Truck Only	76 (39.8%)	185 (39.2%)	79 (47.6%)	93 (40.8%)	111 (39.6%)	54 (50.5%)
Both Veh.	17 (8.9%)	26 (5.5%)	10 (6.0%)	17 (7.5%)	27 (9.6%)	14 (13.1%)
None	8 (4.2%)	45 (9.5%)	7 (4.2%)	15 (6.6%)	14 (5.0%)	9 (8.4%)
Total Sample	191 (100%)	472 (100%)	166 (100%)	228 (100%)	280 (100%)	107 (100%)

Next, average weighted volumes by segment length were calculated in rural and urban areas over the five-year study period so at-fault crashes can be analyzed to account for exposure. **Table 13** shows the AADT, commercial volume, and passenger vehicle volume for rural and urban segments of the four interstates. Rural truck volumes range from approximately 32% on I-70 and I-44 to approximately 13% on I-270 and I-435, and urban truck volumes range from approximately 11% to 21%. Rural passenger vehicle volumes account for about 67% of the total volume on I-70 and I-44 and 87% on I-270 and I-435. Urban passenger vehicles make up approximately 80%-90% of the AADT

Table 13 – Average Interstate Volumes by Classification

Vehicle	Average Volumes and % of AADT							
	I-70		I-44		I-270		I-435	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
AADT	30477	94520	29264	53510	27243	142684	21959	56559
Pass. Veh.	20402 (66.9%)	80526 (85.2%)	20221 (69.1%)	42137 (78.7%)	24092 (88.4%)	126260 (88.5%)	18785 (85.5%)	49420 (87.4%)
Commercial	10076 (33.1%)	13994 (14.8%)	9043 (30.9%)	11373 (21.3%)	3150 (11.6%)	16424 (11.5%)	3174 (14.5%)	7140 (12.6%)

An at-fault crash rate for a section (**Equation 1**) is calculated for each year during the study period in order to perform a t-test for significant differences in at-fault between passenger vehicles and trucks. The at-fault crash rates are calculated using the at-fault crash data for each type of severity shown in **Tables 14, 15, and 16**. It should be noted that the rural I-270, rural I-435, and urban I-435 fatal scenarios as well as the rural I-270 and rural I-435 disabling and minor injury scenarios had two or fewer crashes and therefore were not included in the analysis.

Table 14 – No. of Fatal At-Fault Crashes by Year and Classification

Year	Fatal At-Fault (# of crashes)									
	I-70				I-44				I-270	
	Rural		Urban		Rural		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	4	1	4	0	6	0	5	0	1	0
2003	5	1	3	0	4	0	5	0	2	0
2004	6	2	0	1	4	3	1	0	1	0
2005	4	0	3	0	8	4	5	3	0	0
2006	3	1	3	3	4	0	2	3	0	1

Table 15 – No. of Disabling Injury At-Fault Crashes by Year and Classification

Year	DI At-Fault (# of crashes)											
	I-70				I-44				I-270		I-435	
	Rural		Urban		Rural		Urban		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	9	6	10	6	21	8	9	3	6	5	0	0
2003	7	3	9	3	11	4	11	3	2	3	1	0
2004	7	5	18	6	10	2	7	1	4	5	2	0
2005	9	5	9	3	14	8	5	5	1	3	2	0
2006	4	4	7	3	12	3	6	6	7	0	1	2

Table 16 – No. of Minor Injury At-Fault Crashes by Year and Classification

Year	MI At-Fault (# of crashes)											
	I-70				I-44				I-270		I-435	
	Rural		Urban		Rural		Urban		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	24	19	43	40	11	15	19	17	21	20	9	6
2003	17	15	50	29	13	21	20	21	37	24	7	15
2004	17	13	40	43	13	7	20	12	20	29	3	11
2005	20	20	55	32	17	19	18	22	17	18	4	6
2006	12	9	28	41	16	17	26	21	33	20	7	16

Crash rates for a section are commonly used in traffic safety practice to determine corridors with higher incidence of certain crash types while accounting for exposure through volume and length of the corridor instead of just analyzing the number of crashes. It is true that crash locations are random, but crash types are not and usually occur on similar sections of roadway. This is cause for a more detailed rate such as an at-fault crash rate in order to determine which vehicles are actually causing the crashes.

Tables 17, 18, and 19 give yearly crash rates for each interstate scenario as well as a five-year average. Fatal crash rates are fairly low for most scenarios due to the lower numbers of these types of crashes; however, passenger vehicle fatal at-fault crash rates in rural settings are highest among all fatal crash rates. Disabling injury trucks at-fault crash rates are almost always higher than passenger vehicle rates and significantly higher in minor injury crashes. This, as well as the increase of truck at-fault crash rates from rural to urban areas, is supportive of the notion that trucks may contribute more to crashes than their respective volume. Further analysis of these rates through crash rate ratios may support or debunk the aforementioned assertions.

Table 17 – Fatal At-Fault Crash Rates by Year and Classification

Year	Fatal Crash Rate (At-Fault Crashes per 100 Million Vehicle Miles)									
	I-70				I-44				I-270	
	Rural		Urban		Rural		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	0.326	0.165	0.157	0.000	0.434	0.000	0.316	0.000	0.062	0.000
2003	0.408	0.165	0.118	0.000	0.289	0.000	0.316	0.000	0.124	0.000
2004	0.489	0.330	0.000	0.226	0.289	0.485	0.063	0.000	0.062	0.000
2005	0.326	0.000	0.118	0.000	0.578	0.646	0.316	0.703	0.000	0.000
2006	0.245	0.165	0.118	0.678	0.289	0.000	0.126	0.703	0.000	0.476
Avg.	0.359	0.165	0.102	0.181	0.376	0.226	0.228	0.281	0.050	0.095

Table 18 – Disabling Injury At-Fault Crash Rates by Year and Classification

Year	DI Crash Rate (At-fault Crashes per 100 Million Vehicle Miles)											
	I-70				I-44				I-270		I-435	
	Rural		Urban		Rural		Urban		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	0.734	0.991	0.392	1.355	1.518	1.293	0.569	0.703	0.372	2.381	0.000	0.000
2003	0.571	0.496	0.353	0.678	0.795	0.646	0.696	0.703	0.124	1.428	0.126	0.000
2004	0.571	0.826	0.706	1.355	0.723	0.323	0.443	0.234	0.248	2.381	0.251	0.000
2005	0.734	0.826	0.353	0.678	1.012	1.293	0.316	1.172	0.062	1.428	0.251	0.000
2006	0.326	0.661	0.275	0.678	0.867	0.485	0.379	1.406	0.434	0.000	0.126	1.741
Avg.	0.587	0.760	0.416	0.949	0.983	0.808	0.481	0.844	0.248	1.524	0.151	0.348

Table 19 – Minor Injury At-Fault Crash Rates by Year and Classification

Year	MI At-Fault (At-fault Crashes per 100 Million Vehicle Miles)											
	I-70				I-44				I-270		I-435	
	Rural		Urban		Rural		Urban		Urban		Urban	
	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck	Psg. Veh.	Truck
2002	1.958	3.139	1.688	9.034	0.795	2.424	1.202	3.984	1.301	9.523	1.132	5.222
2003	1.387	2.478	1.962	6.549	0.939	3.393	1.265	4.921	2.292	11.427	0.880	13.056
2004	1.387	2.147	1.570	9.711	0.939	1.131	1.265	2.812	1.239	13.808	0.377	9.575
2005	1.632	3.304	2.159	7.227	1.228	3.070	1.138	5.155	1.053	8.571	0.503	5.222
2006	0.979	1.487	1.099	9.259	1.156	2.747	1.644	4.921	2.044	9.523	0.880	13.927
Avg.	1.468	2.511	1.695	8.356	1.012	2.553	1.303	4.358	1.586	10.570	0.754	9.400

Once the at-fault crash rates were calculated, the five-year rates for passenger vehicles versus trucks were tested for significant differences to distinguish whether the at-fault percentages are significant. A t-test assuming unequal variances was performed for each scenario at a 95% confidence level ($\alpha=0.05$) and the results are tabulated in **Table 20**. The results of the t-test for fatal at-fault crash rates show that only in the I-70 rural scenario are the passenger vehicle and truck differences statistically significant. The disabling injury crash rates show statistically significant differences for the I-70 and I-270 urban scenarios. All minor injury at-fault crash rates were found to be statistically significant as well.

Table 20 – Statistical Significance of At-Fault Crash Rates

Interstate Location		Statistical Significance of At-Fault Crash Rates					
		Fatal		Disabling Injury		Minor Injury	
		t-Statistic	P(T<=t) one-tail	t-Statistic	P(T<=t) one-tail	t-Statistic	P(T<=t) one-tail
I-70	Rural	2.902	0.00992	-1.532	0.082086	-2.825	0.01508
	Urban	-0.585	0.2949	-2.923	0.013257	-10.334	7.3E-05
I-44	Rural	0.982	0.18557	0.703	0.252505	-3.869	0.00901
	Urban	-0.296	0.38959	-1.685	0.076374	-6.870	0.00118
I-270	Urban	-0.466	0.33271	-2.886	0.022366	-9.315	0.00012
I-435	Urban			-0.561	0.302218	-4.649	0.00483

*The I-435 Urban scenario had a low frequency of fatal crashes and was not included in the analysis of at-fault crash rates.

The truck at-fault crash rate versus passenger vehicle at-fault crash rate ratio (RSEC ratio), seen in **Tables 21, 22, and 23**, is calculated for fatal, disabling injury, and minor injury crashes using the summation of the five-year at-fault crash results of **Tables 14, 15, and 16** divided by the volumes in **Table 13**. The RSEC ratio is also shown as **Equation 2** in the methodology section of the report. Passenger volumes divided by truck volumes are also displayed to show the relative proportions of AADT. A ratio greater than one signifies a greater truck at-fault crash rate than passenger vehicle at-fault crash rate. For example in the urban I-70 scenario, the commercial vehicle represents 4 at-fault fatal crashes with a volume of 13,994 while passenger vehicles represent 13 of the fatal crashes with a volume of 80,526. Therefore, multiplying 4 by 80,526 and then dividing by the product of 13 and 13,994 results in an RSEC ratio of 1.77. It should be noticed that in all types of severity the RSEC ratio is always larger in an urban area than it is in a rural area. This could be because as volume increases so does the interaction between trucks and passenger vehicles which may cause trucks to be more prone to being at fault in crashes. An overall look shows that in all severity types the RSEC ratio is close to doubled from rural to urban. When comparing RSEC ratios versus passenger vehicle volume to truck volume, trucks seem to be overrepresented in at-fault in all areas except rural fatal and disabling injury crashes. Passenger vehicles overall do not have a greater at-fault crash rate than trucks, except for the rural fatal crash scenario where the ratio is 0.460 and 0.602 for I-70 and I-44.

Table 21 – Fatal RSEC Ratios

	Fatal RSEC Ratios				
	I-70		I-44		I-270
	Rural	Urban	Rural	Urban	Urban
RSEC Ratio	0.460	1.771	0.602	1.235	1.922
Pv/Tv	2.025	5.754	2.236	3.705	7.688

Table 22 – Disabling Injury RSEC Ratios

	Disabling Injury RSEC Ratios					
	I-70		I-44		I-270	I-435
	Rural	Urban	Rural	Urban	Urban	Urban
RSEC Ratio	1.294	2.280	0.822	1.755	6.150	2.307
Pv/Tv	2.025	5.754	2.236	3.705	7.688	6.922

Table 23 – Minor Injury RSEC Ratios

	Minor Injury RSEC Ratios					
	I-70		I-44		I-270	I-435
	Rural	Urban	Rural	Urban	Urban	Urban
RSEC Ratio	1.710	4.928	2.524	3.345	6.667	12.459
Pv/Tv	2.025	5.754	2.236	3.705	7.688	6.922

It is now useful to compare both the RSEC ratios and the statistical significance of the at-fault crash rates, which is seen in **Table 24**. When looking at the fatal truck-passenger vehicle crashes, the only scenario with a statistically significantly different at-fault crash rate is I-70 rural, while the RSEC ratio is less than 1. The RSEC ratio indicates a passenger vehicle overrepresentation of at-fault to volume and may be concluded that in this scenario, passenger vehicles are less safe than trucks. In disabling injury truck-passenger vehicle crashes, no statistical significance was shown between the two at-fault crash rates in any scenario, but the

RSEC ratio is consistently greater than one. The lack of statistical significance in crash rates could be explained by the variance in crash numbers among the five years. It is concluded that in most disabling injury crashes, trucks can be considered more at fault than passenger vehicles, but not by a significant margin. Minor injury crash rates seem to indicate that trucks are more often less safe than passenger cars due to the high RSEC ratios combined with the significant differences between truck and passenger vehicle at-fault crash rates.

Table 24 – RSEC Ratio vs. At-Fault Crash Rate

Interstate Location		RSEC Ratio vs. At Fault Crash Rate Significance					
		Fatal		Disabling Injury		Minor Injury	
		RSEC Ratio	At Fault Crash Rate Significant?	RSEC Ratio	At Fault Crash Rate Significant?	RSEC Ratio	At Fault Crash Rate Significant?
I-70	Rural	0.46	Yes	1.294	No	1.71	Yes
	Urban	1.771	No	2.28	Yes	4.928	Yes
I-44	Rural	0.602	No	0.822	No	2.524	Yes
	Urban	1.235	No	1.755	No	3.345	Yes
I-270	Urban	1.922	No	6.15	Yes	6.667	Yes
I-435	Urban			2.307	No	12.459	Yes

*The I-435 Urban scenario had a low frequency of fatal crashes and was not included in the analysis of at-fault crash rates.

CONCLUSION

In summary, trucks were found to travel 2.27 mph slower than other vehicles on urban interstates and 3.5 mph slower on rural interstates. The result was statistically significant for rural but not for urban interstates. There was no significant difference in rural speed differentials between daytime and nighttime. The rural data could be further analyzed to determine if speed differences change between congested and non-congested daytime hours.

The lane-use results primarily follow one's intuition that large trucks attempt to travel in the middle lanes in urban areas. However, when there are four lanes per direction present on the interstate, trucks were observed traveling in the two fastest lanes possibly caused by specific situations pertaining to the freeway segments. In most observed situations on urban interstates in Missouri, restricting trucks to the farthest right-hand lanes would encourage these vehicles to the lanes where most weaving on and off the interstate occurs. Lane restrictions should be considered on a case-by-case basis after a study of lane usage is performed; the practice may be useful when truck traffic is more heavily intra-city based than inter-city based.

RSEC ratios exhibit that truck at-fault in crashes seem to be overrepresented in all areas except rural fatal and disabling injury crashes. In all severity types the RSEC ratio is almost doubled or more from rural to urban. Passenger vehicles overall do not have a greater at-fault crash rate than trucks.

Even though the reasons for the disproportionately higher RSEC ratios (urban) for trucks are not clear, the following are presented as possible issues in consideration, both for and against:

- performance characteristics of trucks: braking, acceleration, driver visibility
- length of trucks leading to greater number of interactions per physical space
- formal training of commercial drivers
- the length of commercial truck trips
- behavior of passenger vehicles near trucks
- the different nature of rural versus urban truck-passenger vehicle interactions

Passenger vehicle fatal at-fault crash rates in rural settings are highest among all fatal crash rates, which supports the corresponding fatal RSEC ratios. The fatal at-fault crash rates show that only in the I-70 rural scenario are the passenger vehicle and truck rates statistically different.

Disabling injury at-fault crash rates are almost always higher than passenger vehicle rates and significantly higher in minor injury crashes. It is concluded that in most disabling injury crashes, trucks can be considered more at-fault than passenger vehicles, some scenarios more significant than others. All minor injury at-fault crash rates were found to be statistically significant. Minor injury crashes demonstrate that trucks are more often a safety hazard than passenger cars due to the high RSEC ratios combined with the significant differences between truck and passenger vehicle at-fault crash rates.

Finally, a brief note about statistical tests and their significance is presented here. In assessing differences between the population of trucks and passenger vehicles, statistical tests such as the t-test were employed. For example speed differences and crash rate differences were analyzed

statistically. Sometimes, the differences were not found to be statistically significant. This, however, does not mean that those differences were not significant in every sense of the word. It simply meant that the differences could not be validated statistically. Since the statistical tests that were employed relied on the average values of speeds and crash rates, they were influenced by the variability in the data, the sample size, and the underlying distributional characteristic of the data. Thus, the results that were not found to be statistically significant could still have value for analyzing truck-passenger car interactions.

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APPENDIX

Sample Matlab Code for Filtering I-70 EB Rural Crashes

Summary of Functionality:

- input crash records from MoDOT TMS format
- filter out records that were located at freeway interchanges
- filter out crashes not involving at least one truck and one passenger vehicle
- categorized at fault using probable contributing circumstance
- classify 'passenger vehicle only', 'truck only', 'both', or 'none' at fault.

```
% Project: MoDOT Truck Study
% P.Is: Derek Vap and Dr. Carlos Sun
% Purpose: Process the Crash Data and Analyze "At-fault Percentages of Trucks and Passenger Cars"
% Developed By: Venkat Chilkuri & Derek Vap
% Date: 5/1/2007
% Modified on: 9/4/07
% Matlab Version: 6.5 Release 13.0.1

clear all; % clear all memory

% Select the tab delimited file for reading the input data
% command "uigetfile" might not work in Matlab version 7

[file_name, path_name, filterindex] = uigetfile('*.txt', 'Select Tab-Delimited Accident Datafile');

%Read Input Data
[accNum,tdate,hwyClass,locStreet,lsForm,drvID,vehBodyTypeNum,vehBodyType,contribCode,contrib2Fault,atFault,contribCircum,rdAlign,rd
Profile,lightCond,weatherCond,rdCond,dup_accNum,dup_tdate,dup_hwyClass,dup_locSt,distFeet,distMile,intrsecLoc,crossStreet,twyId,twyNam
e,dir,log]=textread(file_name,'%n%n%s%s%s%n%n%s%s%s%s%s%s%s%s%n%s%s%n%f%s%n%n%s%f%*[\n]', 'delimiter','\t','h
eaderlines',1);

% Column 9 which is Contributing code is changed from number to string because one of the row 182 had a value "U" instead of a
number
%*[\n] reads and discards until the next line feed

%Part 2
% convert date to numbers
date=datenum(tdate);
N=length(accNum); % find the length of the arrays, i.e. number of accident records
% in comparing dates, need to transform using datenum or datevec first,
% since dates have the single quotes stored in the string and creates
% problems in matlab

% create doubly-linked list of accidents since it is easier to collapse
%
for i=1:N, % for each accident
    node(i,1)=i; % set the node number = acc record #
    node(i,2)=i-1; % set the pointer to the previous node as the previous consecutive node
    node(i,3)=i+1; % set the pointer to the next node as the next consecutive node
    % note that the last node will be pointing to an invalid node
end
% remove redundant records if the same image #
for i=1:N, % for each record
    for j=i+1:N, % search for records with the same image #
        if (node(i,3)~=0)&&(node(j,3)~=0) % check only if nodes are still active
            if accNum(i)==accNum(j) % if same image number
                node(node(j,2),3)=node(j,3); % set node j's previous node's next pointer to node j's next pointer
                node(node(j,3),2)=node(j,2); % set node j's next node's previous pointer to node j's previous pointer
                node(j,2)=0; node(j,3)=0; % remove node j's connections, don't know if this is really necessary
            end
        end
    end
end
end
```

```

end

% End of Part 2 i.e creating a linked list

% Part 3
count_pcFault=0;
count_truckFault=0;
yes='Y';
no='N';
E='E';
W='W';
d=datevec(date);
accrec(1,:)= [0 0 0 0];
count_uni=0;
i=1;
temp=0;

while (i<=N)&&(node(i,3)~=0), % search until end of records
    j=node(i,3)-1; % j is the next node pointed by i

    if j<=N % this is to make sure j is not pointing out of bounds of the array

        if j-i~=0 % this is to delete accident records with just one vehicle involved
            if (twyName(i,j,1)==70) & strcmp(dir(i,j,1), E) & ((log(i,j,1)>=23.124 & log(i,j,1)<=101.118) | (log(i,j,1)>=106.375 &
log(i,j,1)<=122.764) | (log(i,j,1)>=131.905 & log(i,j,1)<=203.764)) % this is to only include accident records on I-70 EB rural
                if d(i,j,1)==2006 % this is to report only accidents that happened in 200X - may delete if want all 5 years
                    if ~all(vehBodyTypeNum(i,j,1)>=20) % this is to delete accident records that do not involve both pax. veh. and trucks

                        if (distFeet(i)==0) & (distMile(i)==0.0) % this is to exclude accident records near interchanges, exits, etc.
                            temp=temp+1;
                        else
                            distFeet(i)
                            distMile(i)
                            count_uni=count_uni+1;
                            count_pcFault=0;
                            count_truckFault=0;
                            res_Fault=-1;

                                for k=i:1:j % this for loop counts the number of trucks and pax. cars at fault for each unique accident record
                                    if strcmp( contrib2Fault(k), yes)
                                        if vehBodyTypeNum(k)>=20
                                            count_truckFault=count_truckFault+1;
                                        else
                                            count_pcFault=count_pcFault+1;
                                        end
                                    end
                                end % end of for k=i:1:j loop

                                if (count_truckFault >0) & (count_pcFault>0)
                                    res_Fault=2; % 2 is the code for both pax. car and truck at fault
                                elseif count_pcFault >0
                                    res_Fault=1; % 1 is the code given for pax. car only at fault
                                elseif count_truckFault >0
                                    res_Fault=0; % 0 is the code given for truck only at fault
                                elseif (count_truckFault==0) & (count_pcFault==0)
                                    res_Fault=-1; % -1 is the code given when no vehicles are considered at fault

                                end

                                accrec(count_uni,:)= [accNum(k) count_truckFault count_pcFault res_Fault];

                                end % end of distFeet(i)>0 & distMile(i)>0 loop
                                end % end of ~all(vehBodyTypeNum(i,j,1)>=20) loop
                                end % end of d(i,j,1)=2004 loop
                                end % end of twyName(i,j,1)=70 loop
                                end % end of if j-i~=0 loop
                                end % end of if j<=N loop
                                i=node(i,3); % point to next node
                            end % end of while loop through all vehicles

```

```
% Part 4: Writing the results to an output file
fid=fopen('results.txt','w'); % results file
fprintf(fid,'%s \n',file_name); % include file name in output file
fprintf(fid,'NumOfAccidents\tFault_TrucksOnly\tFault_CarsOnly\tFault_Both\tFault_Neither\n'); % print output file header

numofAcc=size(accrec,1);
trucks=length( accrec(accrec(:,4)==0));
pc=length( accrec(accrec(:,4)==1));
both=length( accrec(accrec(:,4)==2));
neither=length( accrec(accrec(:,4)==-1));
fprintf(fid,'%d\t%d\t%d\t%d\t%d\n',numofAcc,trucks,pc,both,neither); % save stats
temp
fclose(fid);
```



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