SAFETY EVALUATION OF LARGE TRUCK-PASSENGER VEHICLE INTERACTIONS AND SYNTHESIS OF SAFETY CORRIDORS

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by
DEREK VAP

Dr. Carlos Sun, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

SAFETY EVALUATION OF LARGE TRUCK-PASSENGER VEHICLE INTERACTIONS AND SYNTHESIS OF SAFETY CORRIDORS

presented by Derek Vap,

a candidate for the degree of master of science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Carlos Sun

Professor Mark Virkler

Professor John Fresen

Charles Nemmers

DEDICATION

To my wonderful family, for which I could not live without. I especially thank my parents, Carmen and Greg, for the unconditional love and continuing support. I know that no matter where I go or what I achieve, you will be right by my side to watch me do it……Thanks, Mom & Dad.

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ABSTRACT

Insights into the nature of large truck-passenger car interactions and the understanding of safety corridors can lead to improvements in the safety and efficiency of freeway operations. One main contribution of this thesis is the analysis of truck-passenger car interactions on Missouri urban and rural freeways. The analysis consisted of: (1) comparison of mean, 85th, and 95th percentile speeds, (2) investigation of large truck lane usage and (3) comparison of at-fault crashes. Contrary to some public perception, there was no evidence that, on the average, trucks were traveling faster than passenger cars. In terms of lane usage in general, trucks concentrated mainly in the middle lanes and avoided the right-most and left-most (median) lanes. In terms of at-fault in crashes, a new method of analysis was developed using the ratio of truck at-fault crash rates versus passenger vehicle at-fault crash rates, or RSEC ratios. The results show that in fatal and disabling injury rural interstate crashes, the passenger vehicle is more at fault. Trucks are more at fault in fatal and disabling injury urban interstate crashes as well as all minor injury rural and urban interstate crashes. The at-fault crash analysis is especially significant since previous studies have shown a different result.

Another main contribution of this thesis is the development of a synthesis of safety corridor programs conducted throughout the country and identifying the most promising practices and programs to disseminate among other state departments of transportation. Several states have developed safety corridor programs for identified corridors with safety issues, including but not limited to high crash frequencies or rates, and use a multi-disciplinary team of engineering, education, enforcement, and emergency medical services (4E) to identify treatments and strategies to improve the safety of the corridor. The purpose of this part of the thesis is to contribute to the safety management programs of the states so as to facilitate implementation of the best practices. Definitions of a safety corridor, possible criterion for selection, measures of effectiveness (MOE's), and other facets of a safety corridor program such as legislation were identified for states which currently have safety corridors. Finally, the thesis will provide a comprehensive list of characteristics and good practices found in safety corridor programs.

CHAPTER 1: INTRODUCTION

A Department of Transportation (DOT) deals with many concerns expressed by its traveling public and need tools to evaluate as well as fix the problems associated with these concerns. One of the constant problems in transportation engineering is figuring out not only how traffic can be moved efficiently, but also how it can be moved safely. The impact that trucks have on the efficiency and safety of interstates including the interactions between trucks and passenger vehicles are of utmost importance. With the numbers of trucks on the road rising each year, increasing truck safety is a key objective in the improvement of the nationwide transportation network. Missouri is a good representative of the truck travel in the United States as it has anywhere from 5% trucks on urban interstates to almost 40% trucks on its rural interstates. This thesis will use the truck-passenger vehicle interactions on Missouri's interstates to be evaluated for safety.

Different strategies being proposed to improve the safety of truck-passenger vehicle interactions include differential speed limits, truck lane restrictions, and even truck-only freeways. The result of this thesis is intended to provide information on truck operations and assist in trucking policy decisions by creating a new method to evaluate the safety between trucks and passenger vehicles. 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.

Once a safety concern has been evaluated, a solution must be developed and implemented to target the problem area(s) of concern. Although truck-passenger vehicle interactions are an important problem in need of fixing, it is only one of many issues that DOTs face. As the field of transportation engineering progresses, it is being realized that human behavior is just as important as physical engineering concepts in understanding the causes of traffic crashes. Many crashes are caused by mistakes made by the driver that are unpredictable and almost impossible to design a roadway for. This is why DOTs are starting to realize the importance of multi-disciplined solutions to traffic safety problems. One of these solutions is the concept of a safety corridor, which uses experts from education, engineering, enforcement, and emergency medical services in order to target roadway hazards and driver behaviors on sections of roadway with high incidences of crashes. A fraction of the state DOTs have some sort of safety corridor program in place, but all are different in their own right. There is a need for a comprehensive look at safety corridor programs across the country and a list of best practices so that DOT efforts for improving safety may be focused efficiently; this thesis fulfills that need.

The fact that a new method for evaluating the safety of truck-passenger vehicle interactions has been developed in this thesis will only improve on the selection criteria used in choosing and implementing a safety corridor as well as all types of transportation safety evaluations.

CHAPTER 2: LARGE TRUCK-PASSENGER VEHICLE INTERACTIONS

2.1 LITERATURE REVIEW AND BACKGROUND INFORMATION

A literature review was performed to determine what kinds of safety evaluations are currently being used for truck-passenger vehicle interactions, as well as methods in providing solutions to the safety hazards caused by these interactions. Measures to be used in this thesis in determining the safety of interactions between large trucks and passenger vehicles 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.

2.1.1 Safety Effects of Differential Speed Limits

The issue of increased truck travel has raised much debate over policies of truck speed limits, restricted truck lanes, and dedicated truck-only lanes. Current 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 and Mera 1994). Harkey and Mera also found that states with a USL had higher car into truck and truck into car crashes than states with a DSL. This defies common sense that would conclude that a greater variance in speed differentials created by a DSL would cause more crashes than a roadway with a USL. A study has also shown that the two types of speed limits do not produce any differences in crash rates (Garber and Gadiraju 1991).

Freedman and Williams (1992) analyzed the difference in speeds between passenger cars and large trucks in states with 55-mph and 65-mph speed limits after Congress enacted legislation in 1987 allowing states to increase speed limits on rural interstates from 55-mph to 65-mph. They concluded that the difference in speed limits is the reason for the large differences in travel speeds. When DSLs are applied, truck speeds tend to be held down creating larger speed differentials and negative effects on safety. A study analyzing the safety impacts of DSL on rural interstate highways found no consistent safety effects of DSL opposed to USL. It found that regardless of whether a USL or DSL was imposed, the mean speed, 85th percentile speed, median speed, and crash rates tended to increase over the 10-year study period (Garber et. al. 2005). Garber et. al. found that despite the differing speed limit policies of maintaining USL or DSL or changing from USL to DSL and vice versa, not a single state saw a significant decrease in any of various crash rates. Crash rates either did not change significantly or significantly increase.

Yet another study indicated through crash analysis that no obvious relationship existed between crash rates and speed limits, and thus no evidence was found to support that either DSL or USL are more beneficial to vehicle safety on rural interstates (Yuan and Garber 2002). In speed analysis, the mean speed of all vehicles on the rural interstate kept a natural increasing trend regardless of speed limit changes. However, reliable results are a function of the quality of the data and the speed results from this study were only as good as the 10-mph bins would allow. More accurate speed trends may have been seen with smaller speed bins.

A report on the policy impact of differential speed limits and trucking regulations concludes that only the maximum speed of trucks affects fatalities involving trucks, and the difference in maximum speeds between passenger vehicles and trucks has no statistically significant impact on safety (Neeley and Richardson 2004). A generalized least squares regression was used to determine the effects of multiple safety factors in truck involved crashes. The fact that large speed differentials were not significant in this study's results is contradictory to traffic engineering studies that have shown a negative safety impact of large speed differentials between trucks and passenger vehicles (Council et. al. 2004).

2.1.2 Safety Effects of Truck Lane Restrictions

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 from Cate and Urbanik's simulation modeling 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. Although no negative effect was found, a definite positive effect was not found either, which leads to the conclusion that the benefits of implementing truck lane restrictions do not significantly outweigh the costs of such a practice.

The Texas Transportation Institute evaluated an eight-mile section of restricted truck lanes in Houston, TX and determined that there was a dramatic 68% reduction in crashes as well as truck compliance rates of 70% to 80% (Borchardt 2002). However, the crash data was only analyzed over a 36 week period after the implementation of truck lane restrictions. These results should be carefully considered because a nine month study period of crashes on a small section of eight miles may not be sufficient to confidently state a reduction in crashes. No indication was given to the time period of the data that these results were compared to either. Before and after studies of crashes should always be wary of the regression to the mean problem.

Truck lane restrictions in Virginia were analyzed for roadways with two lanes and three lanes per direction with differing results (Fontaine and Torrence 2007). Two-lane segments with restrictions showed positive operational and safety improvements: overall crashes declined by 23% and overall average speeds increased by about 5.5 mph. Three-lane segments with restrictions did not see any significant improvements in mobility, but the safety differed substantially between high and low volume sites. The analysis concluded that a reduction in crashes were present on roadways with an AADT less than 10,000 vehicles per lane per day. Crashes were estimated to have increased at sites with truck restrictions exceeding this volume threshold. Compliance rates at the three-lane sites were estimated to be around 94%. This study seems to support the benefits of truck lane restrictions, but it should be noted when interpreting the results that only one year of ‘after’ data was available for statistical analysis. One year provides for an adequate sample size for evaluation of speeds and compliance rates, but caution should be taken in the interpretation of the crash results due to small sample sizes, especially when analyzing sparse occurrences such as fatal and serious injury crashes.

A report by the Texas Transportation Institute presents a methodology for implementing the best solutions for separating trucks from passenger vehicles (Middleton et. al. 2006). Different methods discussed include truck lane restrictions, exclusive truck lanes, and exclusive truck facilities. Each strategy is examined for selection criteria as well as safety benefits, namely truck volumes, overall crashes, truck involved crashes, and roadway levels of service. Costs and benefits for all options as well as strategies for implementation of each option are analyzed.

2.1.3 Driver Fault in Truck-Passenger Vehicle Crashes

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 one study (Council et. al. 2003). The primary approach in Blower’s study (1998) 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 factors which contribute to the crash recorded by the Fatality Analysis Recording System (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. Blower also gives an explanation for the disproportionate percentages of fault attributed to passenger vehicle drivers. The author claims that truck drivers more often survive truck-passenger vehicle collisions and the surviving driver influences the reporting police officer's report, resulting in blame assigned incorrectly to the deceased driver. However, it could also be argued that official investigations usually occur when a crash results in a fatality or serious injury and the true cause of the crash is determined regardless of the surviving driver's account of the collision. The coding of driver-related factors in FARS implies that passenger vehicle drivers contribute more to truck-passenger vehicle fatal crashes, but this statistic alone should not be used to fully assign fault. Exposure should be taken into account by using volumes which will be performed and analyzed in the remainder of this thesis.

Stuster (1999) developed a set of 26 unsafe driving acts (UDAs) of passenger vehicle drivers in truck-car crashes. The UDAs 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. The paper implied that the higher percentage of passenger vehicles coded with a primary collision factor meant that they bore the responsibility in the majority of truck-passenger vehicle crashes. However, there was no effort to take exposure into account by comparing the fault in crashes to the vehicle's relative proportion of the volume. There is a lack of input on the behaviors of truck drivers who are at fault as well.

In this thesis, 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 at-fault percentages of truck-passenger vehicle fatal and injury crashes. All of these processes help in evaluating the safety of truck-passenger vehicle interactions.

2.2 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 visually 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 2,411 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, disabling injury, and minor injury 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.

2.3 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 thesis 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, there were concerns about using SMS in the urban area and TimeMS in the rural area; it would be difficult to make comparisons using the two different measures of speed. 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. See **Appendix** for a copy of the MUAR. For the remainder of the thesis, 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. It is advantageous that speeds were obtained in such small bins and it can be concluded that speed results are considerably accurate. 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 the 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 on all Missouri interstates. 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. This is a method for evaluating safety as most previous crash rates simply incorporated the frequency of crashes, and not specifically at-fault crashes. 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 are 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

- $\text{T/P}\,(RSEC_{AF}) = \dfrac{100{,}000{,}000 \times C_{(T/P)AF}}{365 \times T \times V_{T/P} \times L}$, where

T/P $(RSEC_{AF})$ = Truck/Passenger vehicle at-fault crash rate for a section, crashes/100,000,000 VMT
$C_{(T/P)AF}$ = # of Truck/Passenger vehicle at-fault crashes, crashes
T = time frame of analysis, years
$V_{T/P}$ = Average Annual Daily Traffic of Trucks/Passenger vehicles, vehicles
L = length of the section, miles

Now that at-fault crash rates for both trucks and passenger vehicles have been determined for each interstate, a new comparison method called the at-fault crash rate ratios (RSEC ratio) can be derived using **Equation 2**. When dividing the truck at-fault crash rate by the passenger vehicle at-fault crash rate the constant terms cancel out only when the two rates are compared over the same time period and section length; therefore, the RSEC ratio is simply a function of the number of at-fault crashes and volumes. If this ratio is greater than 1, then it means that the truck at-fault 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 at-fault crashes are over represented.

Equation 2: At-fault crash rate ratio

- $RSECratio = \frac{C_{(T)AF} \times V_P}{C_{(P)AF} \times V_T}$, where

RSECratio = At-fault crash rate ratio
$C_{(T)AF} / C_{(P)AF}$ = Truck/Passenger vehicle # of at-fault crashes, crashes
V_T / V_P = Truck/Passenger vehicle volume, vehicles

Although the RSEC ratio is intended to explain the relative fault of a particular vehicle (car/truck) involved in a crash in a specific setting (rural/urban), some may view the at-fault crash rates and RSEC ratios as probabilities of being at fault in a truck-car crash. This is an interesting view and will be discussed further. Although the analysis in this thesis includes more than just one truck and one passenger vehicle involved in a crash (crashes involving *at least* one truck and *at least* one car are analyzed), it could be argued that in a two-vehicle crash, each vehicle has the same probability of being at fault considering that we know nothing else about the driver or vehicle.

The at-fault crash rate, $RSEC_{AF}$, represented in **Equation 1** is the relative frequency of an at-fault crash; if the case is made that an event is defined as the number of at-fault crashes in a million miles traveled, then as the limit increases to infinity the relative frequency becomes a probability. Therefore, $RSEC_{AF}$ can be considered the probability of being at-fault in a crash or P(truck or car AF in crash). Using these terms, the RSEC ratio can now be expressed as a ratio of probabilities: RSEC ratio = P(truck AF in crash) / P(car AF in crash). Furthermore, an at-fault percentage/probability ratio can also be expressed using the conditional probabilities: at-fault percentage/probability ratio = P(car AF | crash) / P(truck AF | crash). The conditional probabilities of a vehicle being at fault given that a crash occurs, however, does not take into account the volumes, or exposure, whereas the RSEC ratio does. The difference between the two is that the RSEC ratio estimates relative fault using volumes and at-fault crashes, while the conditional at-fault percentage/probability ratio expresses the at-fault of a particular vehicle once a crash has occurred. The RSEC ratio can be considered as an estimation of the at-fault percentage/probability ratio. This may help those who tend to look at fault in crashes as probabilities or likelihoods of an event. It should be noted that this discussion is in theory only and considers only two-vehicle crashes. The probability discussion becomes more complicated as the amount of vehicles involved in a crash increases.

The RSEC ratio was developed here to explain fault between passenger vehicles and trucks, and it is assumed that the dissimilar vehicle and driver characteristics play a large part in the ultimate outcome of a truck-passenger vehicle collision. The fact is that the RSEC ratio is not used to describe a probability of an event occurring, but rather it is an expression of relative at-fault of one vehicle to another over the same time period and segment of roadway.

2.4 ANALYSIS AND RESULTS

2.4.1 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		Total
	Truck	Non-Truck		t-statistic	P(T<=t) one-tail	# 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

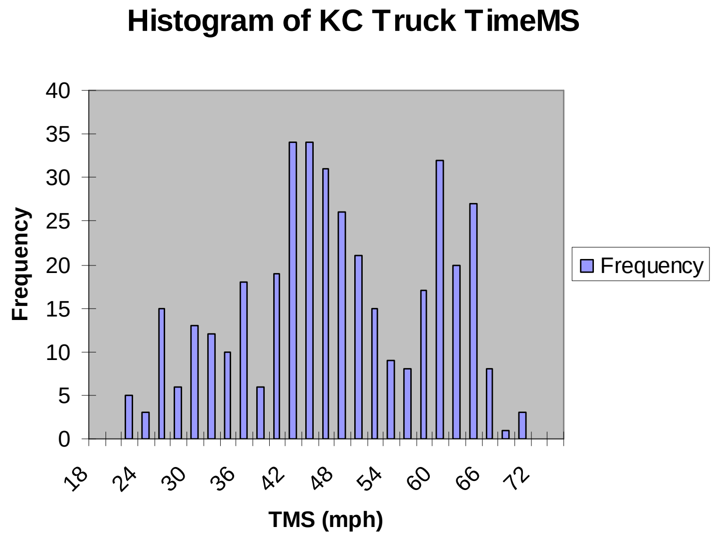
Location	**Avg. TimeMS (mph)**		**Avg. TimeMS Diff. (mph)**	**Stat. Significance**		**Sample Size**				
						Truck		**Non-Truck**		**Total**
	Truck	**Non-Truck**		**t-statistic**	**P(T<=t) one-tail**	**# of Veh.**	**% of Total**	**# of Veh.**	**% of Total**	**# of Veh.**
KC	**46.07**	**48.58**	**-2.51**	**-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**

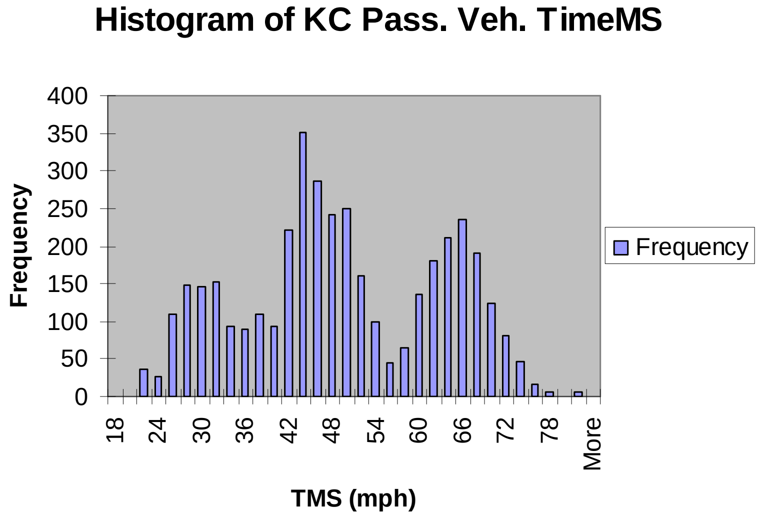
Another measure to look at when determining the safety of highways is the 85th percentile and 95th percentile speeds. The 85th percentile and 95th percentile speeds are the speeds at which 85% and 95% of vehicles observed are traveling below. **Table 3** shows that the 85th percentile speed for all urban 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% of 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.





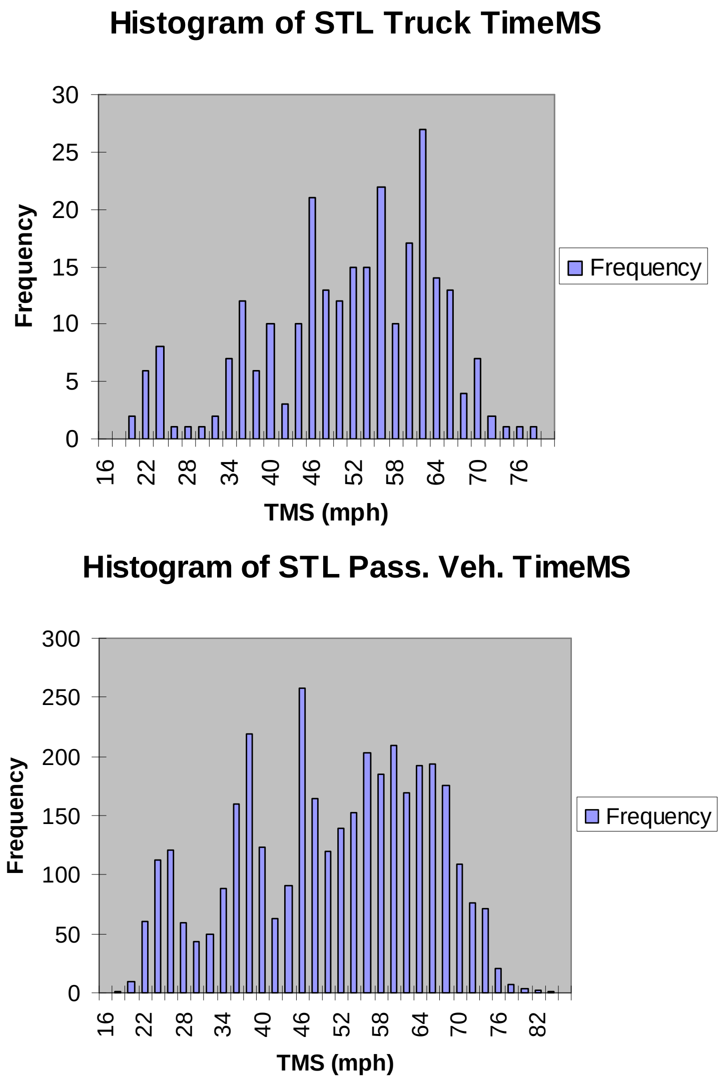


Figure 1 - Histogram of Urban Speeds

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 truck 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 given the changes in overall volumes. **Table 5** demonstrates 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	85th% Speed (mph)		95th % 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.

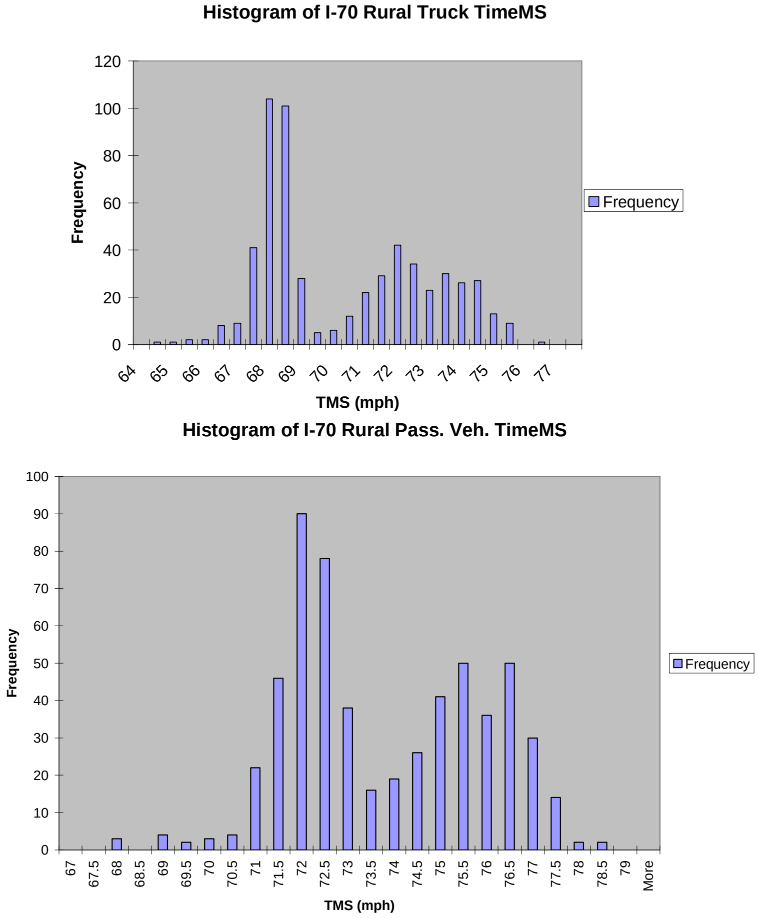


Figure 2 - Histogram of Rural Speeds

2.4.2 Lane Usage

Lane usage in an urban setting may reveal safety issues, because if trucks traveling through a corridor are using the slower lanes nearest the shoulder, this may cause more conflicts between entering and exiting vehicles. Similarly, if trucks are traveling primarily in the faster lanes nearest the median, 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. The results of the lane usage analysis show that the majority of large trucks recognize the safety benefits of traveling primarily in the middle lanes and attempt not to impede merging and weaving vehicles or the faster vehicles in the lanes nearest the median.

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.

2.4.3 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 at fault in almost 20% of the fatal crashes may appear disproportionate when considering truck volumes. Further analysis conducted into at-fault crash percentages versus 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 the 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 analyzed because 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 consistently similar between rural and urban for both trucks and passenger vehicles. More detailed at-fault percentages are shown in **Tables 10, 11,** and **12**.

Table 9 – Selected Interstate At-Fault Percentages by Classification (2002-2006)

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 (2002-2006)

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 (2002-2006)

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 (2002-2006)

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 between approximately 11% and 21%. Passenger vehicle volumes account for about 67% and 69% of the total volume on rural I-70 and I-44 and 87% on I-270 and I-435. Passenger vehicles make up approximately 80%-90% of the AADT on urban interstates.

Table 13 – Average Interstate Volumes by Classification (2002-2006)

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 total 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

	MI At-Fault (# of crashes)											
	I-70				I-44				I-270		I-435	
	Rural		Urban		Rural		Urban		Urban		Urban	
Year	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. Crash rates are typically calculated for all vehicles over a section or sometimes for just trucks or passenger vehicles. When analyzing the safety of interactions between two types of vehicles, it is not enough to only give a crash rate number based on total crashes, but also to determine a rate that explains who is at fault in the crash. Thus, this thesis developed a more explanatory rate called an at-fault crash rate in order to determine which vehicles are more responsible in the truck-passenger vehicle crashes.

Tables 17, 18, and **19** give yearly at-fault 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 truck 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 passenger vehicles when accounting for the 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

	Fatal Crash Rate (At-Fault Crashes per 100 Million Vehicle Miles)									
	I-70				I-44				I-270	
	Rural		Urban		Rural		Urban		Urban	
Year	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

	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	
Year	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

	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	
Year	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

*I-435 urban section had a low number of fatal crashes and was not included in at-fault crash rate analysis.

Now this thesis has developed a new safety evaluation using the ratio of truck at-fault crash rate versus passenger vehicle at-fault crash rate (RSEC ratio), seen in **Tables 21, 22,** and **23**. The RSEC ratios are 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 thesis. 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 are at fault in 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 to passenger vehicle and truck volume (Vp/Vt), 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 I-70 and I-44 rural fatal crash scenarios with ratios of 0.460 and 0.602 , and the I-44 rural disabling injury with a ratio of 0.822.

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
Vp/Vt	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
Vp/Vt	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
Vp/Vt	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 significant difference in at-fault crash rates is I-70 rural, complemented by an RSEC ratio less than 1. The I-44 rural scenario also presents an RSEC ratio less than 1 for fatal crashes. The RSEC ratios indicate a passenger vehicle overrepresentation of at-fault to volume and it is concluded that in the fatal rural scenarios, passenger vehicles are less safe than trucks. These results may be attributed to higher vehicle speeds and significantly greater speed differences on rural interstates as well as the passenger vehicle driver's lack of knowledge of the weight, stopping capabilities, and visibility issues inherent to large trucks. On the other hand, RSEC ratios greater than 1 in **Table 24** indicate that trucks may be more at fault in fatal crashes on urban interstates. This could be explained by the effects of congestion as well as higher occurrences of merging and weaving. Trucks traveling long distances may be accustomed to lower volumes in rural areas and may take for granted the stopping distance or visibility needed to maneuver when encountering situations in an urban setting.

In disabling injury truck-passenger vehicle crashes, a statistically significant difference was only seen between the two at-fault crash rates in the I-70 and I-270 urban scenarios, but the RSEC ratio is consistently greater than one, aside from the I-44 rural scenario. The RSEC ratio in the disabling injury rural I-44 scenario is below 1, and although the difference in crash rates is not statistically significant it may indicate that passenger vehicles are less safe on rural interstates. 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 all 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. This supports the intuitive notion that trucks lack the capabilities to maneuver in a fashion that could prevent minor injury crashes, such as longer stopping distances causing minor rear ending and lack of surrounding visibility causing minor sideswipe crashes.

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

*I-435 urban section had a low number of fatal crashes and was not included in at-fault crash rate analysis.

The development of at-fault crash rates and their corresponding RSEC ratios in this thesis are great new tools for determining the relative safety between trucks and passenger vehicles. An emerging safety topic in today’s traffic engineering society is the concept of safety corridors. Safety corridors are programs that have identified corridors with safety issues, including but not limited to high crash frequencies or rates, and use a multi-disciplinary team to identify treatments and strategies to improve the safety of the corridor. Safety corridors and the process with which they are developed are discussed in more detail in the following sections of the thesis. Criterion for selecting a safety corridor is typically based on the crash history of the roadway. Standard crash rates and frequencies are good tools to measure the safety of a roadway. The at-fault crash rates and RSEC ratios that this thesis has developed provide for another safety evaluation tool in determining the selection of a safety corridor. If it is determined that a roadway is experiencing a high frequency of truck-passenger vehicle collisions, then at-fault crash rates and RSEC ratios may help determine which vehicle drivers to target with engineering, enforcement, and educational countermeasures.

CHAPTER 3: SAFETY CORRIDOR SYNTHESIS

3.1 INTRODUCTION AND BACKGROUND INFORMATION

Several states have developed safety corridor programs. These are programs that have identified corridors with safety issues, including but not limited to high crash frequencies or rates, and use a multi-disciplinary team to identify treatments and strategies to improve the safety of the corridor. This thesis will develop a synthesis of safety corridor programs conducted throughout the country and identify the most promising practices and programs to share among state DOTs and transportation engineering professionals alike. The purpose of the synthesis is to contribute to the safety management programs of state DOTs so as to facilitate implementation of the best practices in safety corridor programs throughout the country. This particular research need was identified by the states of Kansas, Nebraska, Iowa and Missouri at the St. Joseph Safety Forum in March 2006. This is particularly timely as the SAFETEA-LU national highway legislation has provided the states with safety data improvement grants (Section 408 funds) and the FHWA’s Highway Safety Improvement Program (HSIP) Section 1201 directs states to report the top 5% of the high crash roads in the state.

Members of Iowa, Kansas, and Missouri DOTs and respective Federal Highway Administration (FHWA) divisions, along with researchers at Iowa State University’s Center for Transportation Research (CTRE) and the University of Missouri-Columbia’s Civil Engineering department, discussed the advantages of having a comprehensive study of nationwide efforts in safety corridor development in order to more appropriately designate and implement safety corridors in the Midwest. Although the efforts were originally targeted for implementation in the Midwest, the synthesis is applicable nationwide for use in developing a safety corridor program or improving an existing one. Due to the lack of a comprehensive safety corridor program in the Midwest states, this thesis will provide a definition of a safety corridor, possible criterion for selection and methods for filtering high crash locations, measures of effectiveness (MOE's) of safety corridors, organization of safety corridor programs, and other concerns such as legislative issues.

3.1.1 Definition of a Safety Corridor

Currently, there are many differing opinions of what constitutes a safety corridor. Some safety corridors can be a few hundred feet in length containing only a couple of intersections, while others may be a stretch of roadway over 50 miles in length. It was determined that a corridor needs to be somewhat homogenous with reasonably uniform characteristics from beginning to end, no matter what the length. Midwest states have higher concerns for rural two-lane highways; however there is no need to be too narrow when conducting a search for safety corridor programs in other states. The opinion was voiced that urban/suburban locations introduce many more variables and/or problems when developing a safety corridor, but are necessary to analyze nonetheless. An overall consensus was the need to capture what is working in other states in determining safety corridors.

3.1.2 Criterion for Selection and Current High Crash Location Filtering Practices

After a safety corridor is defined, the next logical step is to develop criteria for a state's roadway system to focus on the most dangerous locations. Many states have different query techniques when filtering and targeting roadways in most need of safety improvements. For example, the Missouri Department of Transportation (MoDOT) uses the highest fatal and disabling crash frequencies over a segment. Using a floating window technique with a specified time length and segment length, MoDOT is able to identify the most crucial roadways to improve. MoDOT does not use much crash rate data when identifying problem segments due to lack of understanding by its taxpaying public. Furthermore, since local roads are currently being focused on, another reason that it is difficult to report crash rates at these locations is due to the lack of vehicle miles traveled (VMT) data. The Kansas Department of Transportation (KDOT) filters its top 5% of roads in terms of number of crashes plus a crash rate and develops a combined crash index, then ranks the roads by functional classification. KDOT would like to see the synthesis specifically cover rural corridors and how the programs are disseminated to local jurisdictions. The Iowa Department of Transportation (Iowa DOT) simply uses a crash rate based on fatal and major injury crashes to filter its high crash locations. It can be seen that not one method for filtering high crash locations fits every DOTs needs. Therefore, the methods that identify the corridors with the most promising chances of improving safety need to be determined.

3.1.3 Safety Corridor Measures of Effectiveness (MOE's)

Once safety corridors have been selected and implemented, MOE's must be analyzed to determine if the improvements were beneficial. MoDOT, KDOT, and Iowa DOT all suggested several MOE’s that they often use when checking their safety improvements. Some of the MOE’s include: a reduction in speeds greater than 10 mph, a decrease in 85th percentile speeds, crash reductions, contacts and interviews with drivers, ticketed violations, reduction of DWI’s when relevant, and focusing on the decrease of deaths and injury accidents. All of these suggestions are good MOE’s and more will be documented from states with comprehensive safety corridor programs. Most felt that while crash, death, and injury reductions would be valuable, that statistically it would be a very difficult measure to have confidence in.

3.1.4 States with Safety Corridor Programs

Through research and discussions with other professionals, a total of thirteen states have been identified with some sort of safety corridor program. Not all have a comprehensive program, but some parts of a program with only enforcement, or only engineering from these states can be incorporated to ensure a thorough synthesis. The states that have been identified and studied are: Alaska, California, Florida, Kentucky, Minnesota, New Jersey, New Mexico, New York, Ohio, Oregon, Pennsylvania, Virginia, and Washington.

3.1.5 Other Concerns/Talking Points

The DOTs also voiced other issues of a comprehensive safety corridor program that they would like to be reported in the synthesis. The legal side of enforcement and education in safety corridors is a specific concern for the DOTs. It is also important to know how to achieve approval from legislature to double fines or increase enforcement. Another issue is how the Highway Patrol identifies safety corridor DWI arrests, and alcohol related crashes, etc.

The overall goal for the safety corridor synthesis is not to make specific recommendations for a definition of a safety corridor or MOE’s that can be made, but the main concern is a synthesis of what works in other states and how it can be applied to any DOT in the country.

3.2 OVERVIEW OF CURRENT SAFETY CORRIDOR PROGRAMS

Information collected from the studied programs was attained through informal telephone interviews or meetings with state DOT or FHWA traffic/safety engineering representatives unless otherwise noted from a formal document. State safety corridor contacts and other informational documents can be located in the **Appendix**.

3.2.1 Alaska

In 2006, the governor of Alaska signed into law a bill giving the DOT the ability to designate "Safety Zones" within stretches of highway with unacceptably high fatal and major injury crashes. The legislation may be seen in the **Appendix.** Alaska's main concern is eliminating two-lane, high speed, head-on collisions while following the SAFETEA-LU mandate to focus on severe injury and fatal crashes. Alaska considers traffic safety corridors as a designated "safety zone", similar to a school zone or a work zone. The Alaska DOT, Alaska State Troopers, and the Alaska Highway Safety Office are all involved in the safety corridor program.

Typical elements of Alaskan safety corridors include targeting reckless, intimidating, aggressive, and drunk driving (TRIAD) with a concerted effort of increased education, enforcement, and engineering. Safety corridors are typically two-lane rural highway segments about 10-20 miles in length where violations incur double fines or double points legislation. Incident response is expedited, media campaigns are repeated, and some engineering treatments are used such as special safety corridor signs or center line rumble strips.

Alaska’s criteria for designating a safety corridor are as follows:

- Roadway must be designated as either: interstate, rural major arterial, rural major collector, or rural minor arterial with 2000 ADT or more.
- Roadway must have a 3-5 year fatal + major injury crash rate per mile exceeding 110% of statewide average for rural arterials.
- Roadway must have a 3-5 year fatal + major injury crash rate per 100 million vehicle miles exceeding 110% of statewide average for rural arterials.
- The DOT must agree on a coordinated traffic control/patrol plan.
- It must be agreed that the corridor’s efforts will be effective in reducing crashes.
- The local police define the amount of enforcement needed to increase safe driving and to provide ongoing enforcement.
- No more than 10 safety zones at one time in Alaska.
- The safety corridor should be no shorter than five miles in length.
- The safety corridor is decommissioned when the fatal + major injury crash rate per mile falls below statewide average for a three year period.

A formal education campaign to promote the safety corridor is typically divided into three parts: initial rollout, saturation media, and on-going media. The initial rollout usually begins with the official signing and unveiling of the safety corridor with members of the DOT and other public officials. This event will help to gain publicity for the safety corridor and make drivers aware of the campaign. Other aspects of the initial rollout along with actual safety corridor signing include both television and radio advertisements. The saturation media campaign is a heavy push for publicity for the corridor during the two weeks prior and the two weeks after the designation of a safety corridor. There are also saturation periods during DUI crackdowns and the holiday season. These are specialty advertisements targeted toward the highest ‘risk-takers’, or more specifically, males age 18-35. The education campaign should try to include on-going media efforts such as weekly radio and television spots.

Safety corridor engineering efforts in Alaska include a road safety audit (RSA) to identify possible engineering, education, and enforcement opportunities. Possible short-term and long-term engineering strategies include but are not limited to center line and shoulder rumble strips, upgraded signing, a reevaluation of the posted speed limit, additional lanes/passing lanes, widening of median, addition of median barrier, and changing the roadway geometry. All speed limit signs in the corridor are either upgraded or safety zone placards are added to existing signs, and have no further than three mile spacing. The safety corridor sign shown in **Figure 1** along with an ‘End Double Traffic Fines’ sign legally designate the beginning and the end of the safety corridor.

Figure 3 - Alaska Safety Corridor Sign

3.2.2 California

The safety corridor program is different from all other states' programs in that it is run by the California Highway Patrol (CHP). The program began in 1992 in the Special Projects Section of the CHP. California has general safety corridors as well as problem specific corridors relating to pedestrians, trucks, and DUIs. Defined as a roadway, usually fewer than 50 miles, with a high incidence of injury and fatal collisions over three years, a safety corridor is designated if the crash rate is warranted and a task force is formed for each corridor. Funding is provided for up to six corridors a year and an engineering, enforcement, and education (3E) approach is most often used.

The task forces are made up of members from the California DOT (CalTrans), Council of Governments, assorted planning groups, fire and police departments, legislative members, and citizen groups. The task force will meet approximately four times during the 12-month program operations phase, conduct a field review, draft a Safety Action Plan (SAP) that is updated at each meeting complete with a compilation of recommendations, and develop a logo and a slogan for the corridor to use in public education campaigns. Many different attributes of the corridor are discussed when considering possible solutions, such as primary collision factors, types of collisions, the time of day, and collisions by month. Potential short and long-term solutions are written in the SAP to address the corridor's main contributing problems to crashes. The task force must implement at least two of the potential solutions, usually these being overtime enforcement and a public awareness and education campaign. The overall goal of a safety corridor is to decrease fatal and injury crashes by 10%.

3.2.3 Florida

Florida does not have as formal of a safety corridor program as some other states, but the Florida Department of Transportation (FDOT) sets up locally-based groups of highway safety advocates called Community Traffic Safety Teams (CTSTs). The CTSTs are committed to solving traffic safety problems through a comprehensive, multi-jurisdictional, multi-disciplinary approach. The CTST is comprised of members from the city, county, state, and occasionally federal agencies as well as private industry representatives and local citizens formed for one city, an entire county, portions of counties, or multiple counties. A common CTST goal is to reduce the number and severity of traffic crashes within the community by focusing on the driver behaviors, the vehicle, the roadway, and pedestrians. For corridors that are focused on by the CTSTs, the length and number of projects is very heavily dependent on the amount of funds available. Each district uses both frequency and severity of crashes as criteria for selection.

Analyses of crashes is done before and after countermeasures are put in place to look for trends and specific areas to target with minor engineering projects, education programs, and extra enforcement. Each FDOT district has a CTST coordinator working with the teams in the district’s area, while the Central FDOT Safety Office is the liaison to the district coordinators. Each CTST has approximately 20 regular volunteer members from the 4E disciplines, with around 60 CTSTs statewide. In 1994 the CTST Coalition was formed to facilitate that sharing of safety programs, ideas, and materials to a statewide audience through the individual CTSTs in Florida.

3.2.4 Kentucky

The Kentucky Transportation Cabinet’s (DOT) safety corridor program applies the 4E concept (3E plus emergency response) over one corridor in each of its 12 districts. These corridors are mostly rural highway through approximately three counties, and over 50 miles in length. Currently, safety conscious planning funds are being used for a half-time safety professional in each of Kentucky’s 15 area Development Districts, which are similar to a regional planning commission. As a part of the planning process for the safety corridor, an RSA is conducted to identify potential low cost engineering improvements to be implemented using specifically budgeted DOT money for this application. Additionally, the DOT may develop supplemental safety programs at high schools that are located within or near the safety corridor.

The process used in identifying safety corridors was developed by researchers at the Kentucky Transportation Center at the University of Kentucky (Green and Agent 2002). First, a list of initial roadways is formulated, usually by length and excluding interstates and parkways. Next, one corridor in each district is selected using these criteria:

- The roadway must travel through more than one county in that district.
- It must be of sufficient length for a corridor (which is typically > 50 miles).
- It must have a relatively high traffic volume.
- It must not be a full control of access highway.
- It must have a relatively high number of crashes (total and injury/fatal).
- It must have a high crash rate (total and injury/fatal).
- It must be above a collector functional classification.

The next step is to rank the corridors in each of the districts using proportions for each attribute as mentioned above by dividing by the maximum value in the district. A subjective relative importance is given to each of these factors using 9 different scoring methods of attribute importance. Lastly, points are totaled for each corridor in the district and the highest total point value is selected for implementation.

A road safety review is then conducted for each of the chosen corridors, including a videotaped drive-through, so that safety characteristics of the roadway, intersections, and driveways may be analyzed. After the road safety review, a crash analysis of the corridor is performed. Crash characteristics such as type, time, and severity are compared with the statewide characteristics for all crashes, and separately for injury or fatal crashes. 0.1 and 0.3 mile spot locations as well as 1.0 mile roadway sections are identified as having the highest number and rate of crashes. After the initial list of high crash locations and sections is determined, the crash rate for each location is compared to the critical rate for that location to determine a critical rate factor (CRF). Spots and sections with a CRF of 1.0 or greater were further inspected for possible low-cost engineering solutions and enforcement strategies.

3.2.5 Minnesota

Minnesota’s Toward Zero Death (TZD) initiative, a subset of the Comprehensive Highway Safety Plan (CHSP), is a multi-agency partnership including representatives from the DOT, the Department of Public Safety, the Highway Patrol, FHWA, Department of Health, the Center for Transportation Studies at the University of Minnesota, and other local safety partners, counties, and cities. Safety corridors are typically identified as part of the TZD initiative. The goal of the TZD initiative is to raise awareness of traffic safety issues and to develop tools that can be used to reduce the number of deaths and injuries by implementing practical, innovative ideas and best practices developed from research at the University of Minnesota and state agencies.

The TZD program team works with the communities and corridor safety coalitions (similar to Florida's CTSTs) to improve the traffic safety of a designated area through short-term, low-cost alternatives to traditional engineering solutions. The safety corridors employ a 4E concept usually based on the results of a Road Safety Audit (RSA). As part of the CHSP, counties may solicit the DOT for safety corridor funding. In 2005, 27 counties were granted a total of $2 million to assist counties in deploying low cost, systematic, proactive safety improvements such as RSAs, guardrail and turn lane improvements, shoulder widening, enhanced signing, and intersection lighting.

3.2.6 New Jersey

New Jersey's safety corridor program started in 2003 with 13 initial corridors of approximately 10 miles in length. New Jersey's selection criterion is a three step process. First, a scan of all state numbered roads for six or more fatal crashes is performed. Next, roadways with six or more fatal crashes are analyzed in 10 mile segments for 1,000 or more total crashes over the previous three years. Lastly, a crash rate is calculated by roadway cross-sectional type (nine types) and a roadway is selected if the section crash rate is 50% higher than the state crash rate average for that particular roadway cross section. A Safety Impact Team made up of representatives from the New Jersey DOT, FHWA, and the National Highway Traffic Safety Administration (NHTSA) typically conduct a Road Safety Audit and based on the findings use a multi-disciplined approach of enforcement, education, and engineering to make short and long-term recommendations. Safety corridors carry double fines for certain violations through enacted legislation as well as signs marking the section of roadway that read “Safe Corridor”. Half of all fines collected in the safety corridors are deposited into the Highway Safety Fund.

All of New Jersey’s safety corridors are located in urban areas; therefore, many crash types are caused by congestion and access management problems. Typical engineering countermeasures include improved signal timing and coordination, updated signing and striping, maintenance issues, and pedestrian safety improvements. To measure the effectiveness of a safety corridor, New Jersey uses a crash reduction approach. Fatal, injury, property damage only, and total crashes are all analyzed for decreases from previous years. Approximately every three years, the safety corridors are re-analyzed using the same selection criteria and if the corridor does not make the list it may be decommissioned; otherwise, further efforts and improvements will continue. After the 13 safety corridors were implemented, New Jersey saw around a 7% drop in both injury and total crashes across the board.

3.2.7 New Mexico

New Mexico’s safety corridor program started in 2002 in response to an outcry from communities that truck drivers were using certain routes as shortcuts making the regular users feel unsafe. After letters written to the governor from concerned citizens, the governor contacted the state DOT for help in developing a comprehensive, multi-disciplined safety program. As a result, a program was developed using mainly extra targeted enforcement and double fines for speeding in the safety corridor area. The mission is accomplished by developing and supporting a comprehensive, multi-strategy approach that includes enforcement, deterrence, prevention, media & education, training, legislation & regulation, and data management & analysis. The overall goal is to reduce crashes and fatalities on these segments by at least 20% (NHTSA 2003).

Two pilot programs for each of the six districts in New Mexico began on four and two-lane rural roadways. Traffic patterns and characteristics are studied regionally and roadways with the highest crashes per road mile are analyzed in depth. Statistics of 10 or more injury or fatal crashes per five miles are looked at, and the top 10-15 roadways per district are ranked accordingly. A large part of cooperation is needed with the local jurisdiction as the money is distributed to local enforcement in the area. Local entities' opinion of when and where improvements are needed is very important to the program. Legislation has been passed making any roadway designated as a safety corridor eligible for doubled fines for speeding and operation of headlights may be encouraged.

At the end of three years the crash and fatality data are analyzed, and if it is decided that a significant reduction is made then the safety corridor may be decommissioned and the next roadway on the list is designated. The six basics of the program are a five year crash history on a moving five mile stretch, a crash investigation with review and recommendations, a review of the engineering and law enforcement initiative so as not to overlap efforts, an approval from the district engineer, a public awareness campaign, and a review of the equipment and signage.

3.2.8 New York

New York's efforts in safety corridors are not quite as comprehensive as others. Generally in urban areas, roadways typically a few miles in length are targeted for aggressive drivers. These aggressive driving corridors include a heavy enforcement period over about two weeks combined with some sort of public education effort.

3.2.9 Ohio

Ohio's safety corridor program began in 2004 when the Governor of Ohio charged the Ohio DOT and the Department of Public Safety (DPS) to form a safety task force to target corridors with abnormally high crash frequencies and crash severity tendencies (Ohio DOT 2004). The program that was developed is discussed here, but due to some negative press and the fact that Ohio already has what they consider rigorous safety conscious efforts; it is uncertain whether the safety corridor program will continue to function as such. The Governor's Task Force on Ohio Highway Safety was formed with five members from the DOT (Chief of Staff, Deputy Director of Planning Division, Office of Safety Administrator, Office of Traffic Engineering Administrator, and Office of Technical Services Administrator) and five members form the DPS (Highway Patrol Information Services Section Commander, Highway Patrol Research Administrator, Field Operations Representative, Licensing and Commercial Standards Representative, and Governor's Highway Safety Office (GHSO) Representative). The task force is in charge of designating and analyzing safety corridors in Ohio.

Safety corridors are identified by analyzing the most recent five-year crash data over approximately two-mile sections of similar roadways using these four statistics:

- Statewide crash rate per million vehicle miles traveled (MVMT)
- Statewide five-year average crash density per mile
- Statewide fatal crash rate per 100 MVMT
- Statewide five-year average fatal crash density per mile

Based on these crash trend analyses, a ranking system is used and the top 5% of roadways are targeted. Once a corridor has been identified, the task force will appoint a Safety Corridor Review Team. The team is made up of the corridor's respective DOT District Deputy Director, District Planning Administrator, Office of Safety, Safety Review Team Chair, Highway Patrol District Commander, GHSO Representative, and other members as deemed necessary. The responsibilities of the Safety Corridor Review Team include analyzing the corridor from a 4E perspective, soliciting input from residents and local stakeholders, develop and implement countermeasures, and track the effectiveness of the corridor. No set length is necessary of a safety corridor, and 10 corridors were initially considered.

Ohio uses some of the most statistically rigorous MOE's of any state. Once countermeasures have been put in place for some time, a simple before and after crash count comparison combined with an Empirical Bayesian approach is used to analyze the corridor's countermeasures effectiveness. Reviewed annually, Ohio decommissions the safety corridor if fatal crash statistics used in selection decrease to cause the roadway to drop below the top 5% statewide.

3.2.10 Oregon

Oregon, a leader in safety corridors, began its program with two corridors in 1989. A safety corridor is defined as a stretch of state highway with an incidence of fatal and serious injury crashes higher than the statewide average for similar roadways. Using the 4E (enforcement, education, engineering, EMS) approach, many safety corridors are used as an intermediate step in more permanent safety infrastructure improvements. The safety corridor program that is developed should also be easily applicable to both state and local highways.

The organizational network of the safety corridor program in the Oregon DOT consists of the safety corridor program manager, the traffic roadway engineering section, the crash analysis and reporting section, and the DOT's five geographic regions (ODOT 2006). The program manager oversees the whole program and its guidelines, assures compliance with the guidelines, analyzes data and makes safety corridor recommendations, gives guidance on countermeasures, and reviews annual safety corridor plans. The traffic roadway engineering section analyzes crash data and gives safety corridor recommendations, are key players in the initial designation and decommissioning of a safety corridor, and make important engineering judgment and analysis decisions. The crash analysis and reporting section provides annual safety corridor data for reports and make special data runs. The five geographic regions of the DOT have ownership of local safety corridors, coordinate and develop annual safety corridor plans, plan and hold meetings, and are ultimately responsible for all aspects in the 4E approach.

An initial safety corridor designation team is formed from key players in the safety corridor organizational network. The team is comprised of the DOT safety corridor program manager, the traffic roadway engineering section representative, the regional transportation safety coordinator, the region's traffic engineer, the appropriate district manager, and the region's public information officer. Once the team agrees that the specified roadway section meets the following three designation criteria, they may officially designate the corridor as a safety corridor:

- The roadway must demonstrate a three year average fatal + serious injury crash rate at or above 110% of the latest statewide three year average for similar roadways.
- The state and/or local law enforcement will commit to making the corridor a patrol priority.
- The initial designation team agrees that the length of roadway is manageable from an enforcement and education standpoint. Rural sections may be longer than urban sections.

Once the initial designation team determines that the corridor meets the criteria, it is up to the region's key players to identify a stakeholder list, perform a detailed review of the annual safety corridor data summary and recommendations report to identify problems and possible countermeasures, and then develop and share with the stakeholders an annual Safety Corridor Plan. This Safety Corridor Plan should include an updated stakeholder list, data elements to be tracked, activities planned for the safety corridor during the year, the parties responsible for each action and corresponding time lines, funding resources and amounts, and identification of projects scheduled within the safety corridor. An annual commitment from participating enforcement agencies, a minimum of four quarterly public information efforts, annual review of traffic control devices, and a coordinated effort to identify and develop cooperation between EMS agencies within the safety corridor area must all be included in the Safety Corridor Plan.

Improvements made to the corridor will be determined, sometimes with a RSA performed by a multi-disciplinary team in order to determine short-term countermeasures and low cost projects with minor engineering repairs and upgrades. Planned enforcement efforts targeting risky driving behaviors, timed educational events or campaigns, and EMS enhancements are all important aspects of the Safety Corridor Plan. Safety corridors are always identified with special signs and are usually accompanied with doubled traffic fines. In most cases, there will be additional signing asking the drivers to turn on their lights for safety.

The decommissioning process is handled by the initial designation team and is considered if any one of the following criteria is met:

- The three year average fatal + serious injury crash rate is at or below 100% compared to the three year average for similar roadways.
- Any of the remaining designation criteria are not met.
- Minimum requirements within safety corridor program guidelines are not being performed.
- A continued lack of activity or investment in the safety corridor.

However, a local stakeholder group may ‘adopt’ the safety corridor once it is decommissioned assuming that the group provides meaningful local investment into improving the safety of the roadway.

3.2.11 Pennsylvania

Pennsylvania defines a safety corridor as a section of a highway where double fines are in effect for certain traffic violations. The corridor is marked by signs that clearly inform the motorist of the designation. PennDOT is required to perform a traffic engineering investigation to determine whether a location can be called a Highway Safety Corridor. Legislation went into effect in 2003 that allows double fines to be collected in highway work zones as well as officially designated safety corridors. Double fines are applied for certain traffic violations, such as speeding, reckless driving and tailgating.

A study on six pilot locations was completed in August 2006 where signs were posted indicating “Safety Corridor – Fines Doubled”. Additional traffic enforcement was provided by police as well as coordination with district justices and a public education component. The study found that incidences of speeding were reduced by 2-14% in the safety corridor pilot locations during a six month period following the initiative. The largest reductions in speeding took place in the right lane, where enforcement was the most visible. Participation of the local enforcement community is critical as it is believed that warning signs do not change motorist behavior on their own. Each PennDOT District office can choose suitable locations for designated Highway Safety Corridors. Although enforcement may be the primary objective, engineering solutions and education campaigns are utilized when necessary. For example, two locations are currently being designated in District 6 (Philadelphia and suburban region) and are equipped with all aspects of the safety corridor designation.

3.2.12 Virginia

In 2003, legislation was passed to formally develop a highway safety corridor program on the condition that at least one corridor be deployed by the beginning of 2004. Due to time constraints, the safety corridor program was only developed and implemented for the interstate system; however, a methodology for transferring the current program to the primary system was discussed. Interstates were the easiest to define and develop a program due to their relatively homogenous nature.

In developing the safety corridor program, Virginia was split into three regions with similar traffic patterns, geometrics, and topography characteristics to compare similar roadways. A moving window of 5, 10, and 15 miles at 0.1 mile intervals was initially used in analyzing crash data. Ultimately, a 5 mile window was chosen and it was determined that the minimum length of a corridor would be 5 miles but not too long that it becomes practically unenforceable.

Selection criteria are as follows:

- The crash rate must exceed 125% of the regional average (approximately one standard deviation above average crash rate).
- The Equivalent Property Damage Only (EPDO) frequency must exceed 150% of the regional average on a per-mile basis (PDO=1, injury=8, fatal=20).
- The truck-involved crash rate must exceed overall regional rate.

The rate and EPDO frequency are then normalized by dividing by the maximum rate or EPDO in the region, and then the measures are added to rank and establish priority for implementation. From the crash evaluation, Virginia determined to implement three safety corridors, one in each region.

A media campaign was also organized to gain recognition among travelers of the three implemented safety corridors. Posters, direct mail flyers, billboards and bus placards, and radio public service announcements were all incorporated into the safety corridor program.

Once the three selected corridors were implemented, the measures of effectiveness were generally speed reductions for two of the sites, and an Empirical Bayes crash reduction analysis for the other. Before and after speed reductions for mean speeds, percent of vehicles traveling greater than 15 mph over the speed limit, and the percentage of vehicles compliant with the speed limit were all considered in the original safety corridors.

3.2.13 Washington

Washington State's safety corridor program is headed by the DOT and the Washington Traffic Safety Commission closely cooperating with local agency groups. If the corridor is a state highway, the DOT's Traffic Operations section is the lead, and if the corridor is on a city street or county road, the Highways and Local Programs section is the lead.

Washington uses a 4E approach to the corridors, which have no set maximum or minimum length, with approximately 4-6 safety corridor projects operating at one time. Some corridors range from a suburban 5-lane arterial to a rural 55 mph 2-lane roadway. The criteria for selection of safety corridors are by crash history, including severity of crashes. No exact criteria are used to select a corridor. Once a roadway is selected, the stakeholders go to the site and identify safety concerns and where and what type of collisions are occurring. The safety corridor team meets about two or three times to identify solutions and locations to implement those solutions. The efforts to combat unsafe driving are typically low-cost engineering solutions such as rumble strips and minor re-striping implemented by the local authority, and the Traffic Safety Commission sets up the education program as well as enforcement efforts, although there is no legislation for double fines. In efforts to combat reductions in fines due to litigation, enforcement officers will stamp the ticketed violation bearing the slogan "Traffic Safety Corridor", seen in **Figure 4**, to ensure that the judge will recognize that the offense was committed in a safety corridor. A large kickoff event with local publicity and local dignitaries present is used to notify the public of the safety corridor and the DOT's efforts to make the roadway safer.

Figure 4 - Washington Safety Corridor Stamp

Mr. Vap visited the Safety Corridor projects in southeastern Washington and participated in one of the Vancouver Safety Corridor quarterly team meetings. He observed that the wide diversity on the team (enforcement, community groups, school system, public works, EMS, etc.) introduced perspectives and solutions that were diverse in an environment where everyone was cooperative and supportive. Everyone had a stake in the outcome. Pedestrian accommodation along the corridor (especially crossing the arterial in commercial areas) was one instance where we observed very productive and supportive communications. The outcomes involved several items including: local enforcement focus, special signage, shopping center based communications, access limitations, and pedestrian signal coordination along with a schedule for implementation and funding plan. Evaluation was also discussed but no agreement was reached at this meeting.

An arbitrary time period for Safety Corridor designation is established by Washington DOT/ Washington Traffic Safety Commission and is usually one and a half to two years. Once the DOT believes that the driver behaviors have changed and the roadway is safer because of the Safety Corridor efforts, then the project will be deemed as “completed.” The corridor will then be decommissioned and the safety corridor signage will be removed.

3.3 RESULTS AND EXAMPLES OF IMPLEMENTED SAFETY CORRIDORS

The safety corridor concept is relatively new to the field of traffic engineering. While many DOTs in the past have continuously focused on highway safety through separate programs, many are not multi-disciplined using a 3E or 4E approach to safety. Due to the newness of the programs, most states that have implemented safety corridor efforts do not have significant amounts of data to perform thorough analyses. As an effect of this, comprehensive evaluations of safety corridors were found to be limited. In the following portion of the thesis is a presentation of specific safety corridors in the subject states and their effects on improving highway safety. A combination of rural and urban corridors is described to encompass the broadly ranging solutions to a common problem.

3.3.1 Alaska's Seward Highway Safety Corridor

The Seward Highway Safety Corridor, the first implemented safety corridor in Alaska, is a 27 mile stretch of rural two-lane interstate with posted speed limits of 65 mph and 55 mph (Alaska DOT&PF 2006). Functioning mainly as a commuter and recreational route, daily volumes continuously approach 22,000 vehicles on weekends during the summer months, more than double the AADT. Overrepresented types of crashes include improper lane changing and driver inattention problems, fatal accidents occurring during twilight hours, and non-restrained fatalities. Over 50% of the fatal crashes on this section of Seward Highway were head-on collisions. A study of the highway conditions concluded that the geometrics of the roadway itself were not a major contributing factor; however, increased summer traffic volumes, winter driving conditions, and a diverse mix of roadway users combined with a lack of passing opportunities or slow vehicle turnouts may have contributed to the poor driver behavior due to frustration and a higher incidence of head-on type crashes.

Implemented engineering countermeasures on the Seward Highway Safety Corridor include continuous edge line rumble strips, periodic centerline rumble strips on horizontal curves, additional speed limit signs and high level warning devices on all existing speed limit signs, installation of regulatory and pennant ‘Do Not Pass Signs’ in areas striped for no passing, and creation of additional no passing zones previously not present. Additional targeted enforcement was implemented along the corridor to support the double fines legislation of the corridor. Educational implementations have included changeable message signs informing drivers of extra enforcement, speed radar trailers, ‘It’s Still Winter, Chill Out on the Road’ winter safe driving campaign as well as ‘Click it or Ticket’ and drunk driving media campaigns, and a memorial highway sign program to place signs at locations of fatal crashes.

As of early April 2007, the safety corridor review team has concluded that safety corridors have reduced severe crashes in the short term. More resources are needed to further prevent and reduce crashes. Severe and fatal crashes have been reduced by more than half on the Seward Highway. One fatal collision occurred in the 10 months since implementation, which was a random crash involving a loose tire falling off a vehicle and striking a motorcyclist. There were no severe injury collisions within the designated corridor. The crash rate before the safety corridor implementation was 13.10 per 100 million vehicle miles (MVM) while the after period was 1.22 per 100 MVM. Due to the short duration since implementation, it is too soon to determine if this trend will continue.

3.3.2 California's State Route 41/46 Safety Corridor

State Routes (SR) 41 and 46 are largely rural two-lane routes that run east-west and eventually merge connecting two main north-south routes, US 101 and Interstate 5 (California Highway Patrol 2001). SR 46, infamously known as the roadway where James Dean was killed in the late 1950's, maintained notoriety into the 1990's for its frequency of fatal and injury collisions. Four years of crash data (1992-1995) for the two routes showed 981 total collisions, 31 of which were fatal crashes and 399 injury crashes. Data displayed that the majority of crashes occurred between 1:00 pm and 6:00 pm on Fridays, Saturdays, and Sundays. AADTs were approximately 14,000 vehicles. An assessment by the safety task force concluded that the major contributing factors to the collisions were drifting out of the lane, over correcting off the road, crossing the centerline, poor signage, inadequate shoulders, short merging and passing lanes, poor accessibility and response for EMS due to remoteness of roadway, and a misunderstanding of signs and laws relating to the use of occupant restraints and drinking and driving by a large Spanish-speaking worker population traveling the roadway.

Overtime enforcement efforts were cooperatively shared by three CHP commands and two local police departments to target the most frequent causes of collisions. Officers worked 2,922 overtime hours, assisted motorists 2,837 times, and issued 14,606 citations. Emergency response services were improved along the corridor by installing emergency roadside call boxes throughout, approving funds for several county and city fire departments to purchase the equipment used by emergency responders at traffic collisions, agreements between EMS providers that the closest units would respond to an incident regardless of jurisdictional boundaries, and a CHP helicopter was permanently assigned to the CHP Coastal Division to be specifically utilized for the safety corridor. Among the notable engineering implementations were:

- Raised-profile thermoplastic striping installed where passing only allowed in one direction.
- Centerline rumble strips installed in no passing zones.
- Shoulders were treated with rumble strips and indented-profile thermoplastic striping.
- Certain lane drops were reconfigured to keep merging consistent.
- ‘Stop Ahead’ warning signs and chevrons installed at certain key intersections and curves.
- Signs posted declaring the corridor as a daylight headlight safety section.
- Legislation of double fines in safety corridor as well as signs to inform motorists of double fines.

A variety of education campaigns and materials were employed including two million flyers emphasizing safe driving behaviors as well as posters in restaurants, recreational destinations, and local businesses, local restaurants offered free coffee or soft drinks to customers who mentioned the safety corridor, Spanish-language television and radio PSAs broadcast each weekend, and three kickoff news conferences were held simultaneously at three separate locations along the corridor.

Four years of ‘after’ data (1997-2000) compared to four years of ‘before’ data (1992-1995) show a 35.4% decrease in fatalities, a 26.5% decrease in severe injuries, and a 5.2% decrease in total injuries. An evaluation of fatal plus injury crashes over the same time period for targeted crash types resulted in a 15.4% decrease for unsafe turning, a 35.0% decrease for improper passing, and a 13.5% decrease in DUI fatal plus injury crashes.

3.3.3 Pennsylvania’s Roosevelt Boulevard Safety Corridor

Mr. Vap made a site visit to an urban Safety Corridor in Philadelphia while on a safety scan tour with employees from MoDOT. Experiencing first hand the complications that led to the implementation of a Safety Corridor in a large urban area provided for a better understanding of the different strategies that task forces must use in an urban setting compared to a rural setting.

Home to the 2nd and 3rd “most dangerous intersections” in the nation, a spike in pedestrian fatalities led to the development of the Roosevelt Boulevard Task Force (Anderson 2007). A Delaware Valley Regional Planning Commission (DVRPC) study was performed to inform the Roosevelt Boulevard Task Force of solutions to this corridor. The corridor is an urban section approximately 8 miles in length with over 180,000 people living within one half mile of the Boulevard. The roadway has an AADT of approximately 80,000. From 2001-2005, 133 pedestrian crashes occurred, resulting in 13 fatalities. Roosevelt Boulevard is a 12-lane facility with six local and six express lanes serving both local and regional traffic. The road includes 11 mid-block pedestrian crosswalks and 40 traffic signals within the study area (Vap et. al. 2007).

Roosevelt Boulevard was designated a safety corridor, and improvements were initiated to reduce pedestrian crashes, rear-end crashes, and red light running incidents. Improvements were numerous:

- Roadway redesign
- Signal timing adjustments and coordination
- Speed limit reduction and speed display signs
- Public education
- Increased enforcement, including photo enforcement of red light running
- Legislation changes
- Pedestrian countdown signals
- Posted pedestrian crossing information
- Improved crosswalk demarcation
- Signalized mid-block crosswalks
- Police/Emergency pull-off areas.

Due to the recent implementation of this safety corridor, there are limited results. However, public perception is positive and drivers seem to be more cautious. Since installation of red light running cameras, one intersection has seen a two-thirds decrease from 1500 violations per month to 500.

3.3.4 Virginia's Interstate 81 Safety Corridor

The Interstate 81 Safety Corridor is a 15 mile rural/suburban section located near the Roanoke metropolitan area in mountainous terrain (Fontaine and Read 2007). Posted speed limits are 65 mph at the southern end of the corridor and 60 mph at the northern end. There is no significant congestion and vehicles are usually able to travel at free flow speeds.

Engineering countermeasures included shoulder rumble strips installed in isolated sections where they were previously missing, acceleration and deceleration lanes were extended at four interchanges, six-inch tape markings and raised pavement markers were installed, highway advisory radio was installed throughout the area, and variable message signs were installed on intersecting roadways prior to the ramps and on the mainline. Signs alerting the drivers of the safety corridors were installed at the beginning, end, and periodically throughout the corridor as seen in **Figure 5**.

Figure 5 – Virginia Safety Corridor sign

Educational initiatives included posters, direct mail flyers, bus placards, radio public service announcements, and billboards within the corridor area. Approximately $250,000 has been spent annually on educational efforts using NHTSA grants since the safety corridor program began. Increased enforcement was largely performed using existing Virginia State Patrol resources along with safety grants obtained through the DMV. 1,467 citations were written in 2005 on the corridor, 78.3% of which were cited for speeding.

Results have shown that after the second year of installation, the I-81 Safety Corridor has reduced total crashes by about 28% and fatal/injury crashes by 44% versus what would have been expected based on the crash trends at comparison sites. These crash results were statistically significant. A telephone survey was conducted of residents in the entire VDOT region that the I-81 Safety Corridor was located. Around 52% of drivers surveyed were aware of the safety corridor.

3.3.5 Washington's State Route 14 Safety Corridor

The State Route (SR) 14 Safety Corridor is a 15 mile two-lane rural road that follows along the winding Columbia River Gorge in Southwest Washington. The top three collision causes were determined to be exceeding safe speed, crossing the centerline, and driving under the influence of alcohol. The leading collision types were hitting fixed objects, hitting wildlife, and vehicle overturns. Engineering countermeasures used were installing centerline rumble strips throughout the entire corridor, marking the road with corridor signs, updating signs along the corridor, improving pedestrian warning information for drivers at a nearby State Park, conducting a speed study in the corridor, and installing road condition warning signs using the Highway Advisory Radio system. Education efforts included project kickoff media campaign, a "Designate A Driver" Holiday Campaign at local bars and restaurants, "Heed the Speed on Hwy. 14" signs, public awareness messages on the back of trucks that travel on SR 14, commercial vehicle educational materials and air fresheners handed out at weigh stations, and a project wrap-up and celebration.

Using enforcement that targeted excessive speeding, following too closely, improper passing, and driving under the influence (DUI), the Washington State Patrol with the county sheriff's office reported a 55% increase in DUI arrests, 103% increase in speeding contacts, 158% increase in total contacts, and a 110% increase in traffic warnings. The project lasted for two years, and a 65% decrease in fatal and disabling injury crashes was observed on SR 14 compared to three years prior to implementation (5/13/00-5/13-03 vs. 5/13/04-5/13/06). Total collisions decreased by 19%, alcohol-related collisions were down 57%, the number one cause of crashes, excessive speeding, decreased 37%, and the number one collision type, hitting fixed objects, was down by 17%.

CHAPTER 4: CONCLUSION AND DISCUSSION

A DOT is constantly dealing with issues on how traffic can be moved efficiently and safely. A large portion of today's economy depends on the trucking industry to deliver goods safely and efficiently. The benefits of productive safety evaluations and safety programs are endless. The interstate system in Missouri is considered a major truck route in the United States and it is important that safety is improved. Through research of 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 Missouri's interstates, this thesis developed a new methodology and evaluative tool for assessing the safety between trucks and passenger cars, which in turn will assist in trucking policy decisions.

Once a safety concern has been evaluated, a solution must be developed and implemented to target the problem area(s) of concern, which are addressed by safety corridor programs. The importance of multi-disciplined solutions to traffic safety problems was voiced by professionals in the Midwest, and the need for a comprehensive synthesis of current safety corridor programs and successful practices for implementation. This thesis fulfills the informational gap among state DOTs and provides a forum for dissemination of the best aspects of programs across the nation.

4.1 LARGE TRUCK-PASSENGER VEHICLE INTERACTIONS

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. 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 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 speed results indicate that any changes to a DSL on rural interstates would further increase the speed differential and alter the safety effects between passenger vehicles and trucks. Changes to DSL in the urban interstates may very well increase the speed differential to a significant level and decrease the safety on these interstates. Further research is needed to determine the resulting effects of any actual changes to the speed limit.

In terms of lane usage, trucks concentrated mainly in the middle lanes and avoided the slow and fast lanes. A truck lane restriction policy could lead to a harmful shift to the lane nearest the shoulder where most weaving and interactions with entering and exiting freeway traffic 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.

A newly developed measure of safety between trucks and passenger vehicles, RSEC ratios, exhibits 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 support 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 significantly different. Disabling injury truck 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. 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. All minor injury at-fault crash rates were found to be statistically significant. Discussion of separated truck lanes across Missouri on I-70 and I-44 has sparked interest in the safety benefits of such an action. A complete network of dedicated truck lanes might not be a cost-efficient approach since urban areas as opposed to rural areas are where the disproportionate truck crash rates occur. It may be more efficient to construct urban bypasses rather than a continuously separated freeway for trucks. On the contrary, the RSEC ratios below 1 (passenger vehicles at fault) in the rural scenarios may support the separated truck lanes because it will remove the interactions that passenger vehicles have with trucks on rural interstates.

This thesis has proved that at-fault crash rates combined with RSEC ratios can be an effective measure of the safety of truck and passenger vehicle interactions. These two newly developed analysis techniques can be another instrument in a traffic engineer’s toolbox. At-fault crash rates and RSEC ratios may be especially important in the safety corridor selection process and help to target problem vehicles using a multi-disciplinary approach.

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.

4.2 SAFETY CORRIDOR SYNTHESIS

Safety corridor programs across the United States are similar, but no single program will fit every state's needs. Roadway and crash characteristics differ from state to state, as well as the availability of safety funds. Each state DOT must decide which aspects of the safety corridor process will effectively and efficiently accommodate their organization's needs. A multi-disciplinary 4E approach has proven to be an effective solution to improving a roadway's safety. Sharing and dissemination of information between states is an integral part of our nation's goal to reduce traffic fatalities. This synthesis encompasses the current state of practice in safety corridors across the country and will provide valuable information to DOTs when combating hazardous roadways.

The results of the synthesis in this thesis provide the following list of characteristics and good practices found in safety corridor programs across the nation:

1. **Multi-disciplined**

Most everyone agreed that there was not a single cause for the higher crash frequencies along particular stretches of highway and consequently believed that a group of solutions needed to be considered. This called for a broad based approach to both problem identification and countermeasure selection. The task force teams were most often lead by the state DOT. California's efforts were led by the Highway Patrol and Washington's efforts were many times headed by the local jurisdiction. Regional planning organizations were shown to be important members with special skills in bringing together disparate groups.

<u>Characteristic</u>: A multi-disciplined approach should be used; most states also included Emergency medical providers (the 4th E).

2. **Limited Number**

In general the successful states limited the number of active corridors at one time because they believed that with too many there was a lack of focus and effectiveness. Drivers may become desensitized to the effect of Safety Corridors if too many are implemented. The range of Safety Corridors per state was from three to twelve at one time. Several states started with one or two pilot corridors while some states selected one per DOT district.

<u>Characteristic</u>: Limit the number of corridors at one time; too many become ineffective. Pilot corridors should be developed first.

3. **Crash Data**

The use of crash and fatal/injury data was common among all states in the Safety Corridor selection process. Some states simply used a crash frequency or a crash rate, while others used a combination of frequency and rate for preliminary selection of corridors. A rate of 10% greater than the statewide average for similar roadways was found to be a common statistic. Once the preliminary group of corridor candidates was determined, the states typically used some type of ranking process dependent upon location, volume, severity of crashes, etc. The top three to five corridors were then selected for Safety Corridor analysis, usually starting with one or two pilot corridors. The same data used for selection of a corridor should also be used after implementation of safety measures in performance analysis to ensure consistency.

Characteristic: Crash and death/injury data including rates should be consistently used for selection, evaluation, and decommissioning.

4. Champion

Many successful programs were supported by one ‘figurehead’ or spokesperson. This person, usually working in the state DOT headquarters, was a constant champion for the Safety Corridor program. The champion acted on behalf of the local Safety Corridor task forces in order to provide lines of communication between the state DOT and all of the stakeholders involved. This person will often be an informational source on the corridor process as well as give direction to the task force for avenues of possible funding.

<u>Characteristic</u>: A statewide champion is important in the success of a program by influencing the selection of corridors as well as the distribution of available funding.

5. **Safety Action Plan**

   A comprehensive plan developed by the multi-disciplined task force is important in the Safety Corridor process. The task force should begin drafting a Safety Action Plan (SAP) at the very first meeting outlining the ideas and steps needed to take in order to implement the Safety Corridor. This plan is where the corridor's safety problems, crash history, and 4E mitigation strategies for the duration of the project should be documented. The engineering, education, enforcement, and EMS plans should all be outlined step by step in the SAP before the Safety Corridor is initiated. Throughout the process, the task force should meet regularly (quarterly) to update the SAP, discuss the results achieved, and develop any new strategies needed.

   <u>Characteristic</u>: A multi-disciplined Corridor Safety Action Plan should be developed by a task force which meets regularly for continual review of the plan and strategies.

6. **Legislation**

   Safety Corridor legislation was passed in about half of the surveyed states to establish a beginning and end of the corridor as well as permitting the enforcement of double fines for traffic related offenses. Some states found it difficult to pass such legislation, while others had positive political support. One state innovatively attached the Safety Corridor legislation to the current legislation for double fines in work zones. Legislation gives tremendous support for overtime and targeted enforcement efforts.

<u>Characteristic</u>: Legislation may be passed, basically to establish corridor limits and permit increased fines. This is important in the success of the enforcement efforts.

7. **Special Signage**

   Signs designated specifically for Safety Corridors were often used among the states. Some used black on white regulatory signs to designate the beginning of a safety corridor, some used black on yellow warning signs, while others used white on green informational signs depending on its purpose. Supplemental Safety Corridor placards were added to speed limit signs throughout the corridor as well. The signs need to be easily identifiable and serve a purpose within the Safety Corridor.

   <u>Characteristic</u>: Special signage in safety corridors should be used: "Fines doubled, speed limits, lights on for safety, etc."

8. **Road Safety Audits**

   The FHWA and the State DOTs have for the last several years embarked in a team based safety assessment review process called Road Safety Audits (RSA) as a means of improving the practices/procedures/standards relative to the safety of newly constructed highways. There are well developed guidelines for these audits (FHWA 2006). States with successful safety Corridor programs believe some scanning review should be conducted on the corridors. Many suggested the RSA approach as one that is well established and appropriate for Safety Corridors. A typical RSA process can be found in **Appendix V**.

<u>Characteristic</u>: Road Safety Audits or some scanning review should be conducted on the corridors to ensure a multi-disciplined targeted effort.

9. **Minimal Engineering**

States typically focused on education and enforcement efforts with minimal physical engineering improvements. Safety Corridors were sometimes used as temporary measures of improving safety when a larger engineering improvement was planned in the future (3-10 years). The engineering improvements were based on specific crash types and trends observed in the corridor. Focusing on driver behavior through educational information and enforcement presence were most important in the Safety Corridors.

<u>Characteristic</u>: Usually, minimal to small engineering improvements are made in safety corridors: signage, center-line and edge-line rumble strips, etc.

10. **Length**

The length of a Safety Corridor varied widely from state to state. Some states preferred a length of 3-20 miles, while Kentucky extended their corridors across multiple counties and exceeded 50 miles. The constant in successful programs was that the corridor had similar roadway and driver characteristics throughout. Length of a corridor can have positive and negative aspects: the shorter corridors are easier to enforce while the longer corridors attract a wider population of road users' awareness.

<u>Characteristic</u>: No mandatory length of safety corridors should be specifically set, but should have homogenous characteristics throughout.

11. **Decommissioning**

Most states had some type of decommissioning process incorporated into the Safety Corridor program. Decommissioning is used to avoid desensitizing users to the concept. Decommissioning should take place after measures of safety have been shown to improve, and should use the same measures that were employed in the selection and evaluation process. A good guideline is an increase in safety over two to three consecutive years during implementation.

<u>Characteristic</u>: Decommissioning is important after an improved safety measure is achieved.

12. **Selection Criteria and MOEs**

Most states' selection criteria and MOEs were typically not very scientific or statistically rigorous. As mentioned earlier, simple crash rates or frequencies were calculated and then ranked fairly simply. A couple states used a very rigorous method of ranking high crash corridors dependent upon many factors. Whatever method chosen, the criteria should be able to stand up to statistical tests.

<u>Characteristic</u>: Selection criteria and analysis of MOEs should be more statistically rigorous than are presently.

13. **"After" Data**

Due to the newness of some states' Safety Corridor programs, detailed analyses was difficult to find. "Before" and "after" data are important in determining the success of a Safety Corridor so that the program can constantly increase safety. Statistical analysis of data after implementation was limited in many states, and simple crash frequencies and rates as well as speed distributions were looked at. Driver response to the Safety Corridor is important to determine the effects that the efforts have on the surrounding population.

<u>Characteristic</u>: Most states have limited "after" data and looked at more global data, such as number of crashes, injuries, speeds, etc.; comprehensive "before" and "after" data as well as driver perception is important in the success of a safety corridor.

Funding

Special funding for the Safety Corridors (from NHTSA’s section 402 funds) was provided in at least one state as “seed” money, principally for overtime enforcement. Also small amounts of FHWA’s safety program funds were reserved for minor engineering improvements on corridors (usually at the headquarters office). While funding was small, it leveraged the program.

Pedestrians

Pedestrian issues are very important in the more urban safety corridors, and in two of the corridors the researchers observed, this was a primary issue/problem.

Other

Several interesting items we uncovered that may be of value are:

a. The Vancouver police place a red “Safety Corridor” stamp on their tickets so that the legal process (prosecutors/judges) knows the violation occurred in an area where there is a safety problem/focus.
b. In Kentucky there was a special program for the high schools along the corridor.
c. Motorcycle policed enforcement is prevalent on urban safety corridors.
d. Include traffic court judges on the Safety Corridor team.
e. Washington used Safety Corridor placards on the back of large trucks traveling the corridor to further enhance the designation awareness.

Through research and conversations with engineers at state DOTs, it is a common concern that a review of all safety corridor programs in the nation had not been conducted until this thesis and is valuable in order to disseminate best practices and successful results. A comprehensive synthesis of safety corridors with recommended best practices is an important contribution of this thesis. Safety corridor programs across the nation are similar but one source or framework is needed for consultation when beginning a program from scratch. The best practices may also be used to update an existing safety corridor program in order for a DOT to achieve the full benefits of their resources and efforts.

The fact that a new method for evaluating the safety of truck-passenger vehicle interactions has been developed in this thesis only improves on the selection criteria used in choosing and implementing a safety corridor, as well as all types of transportation safety evaluations.

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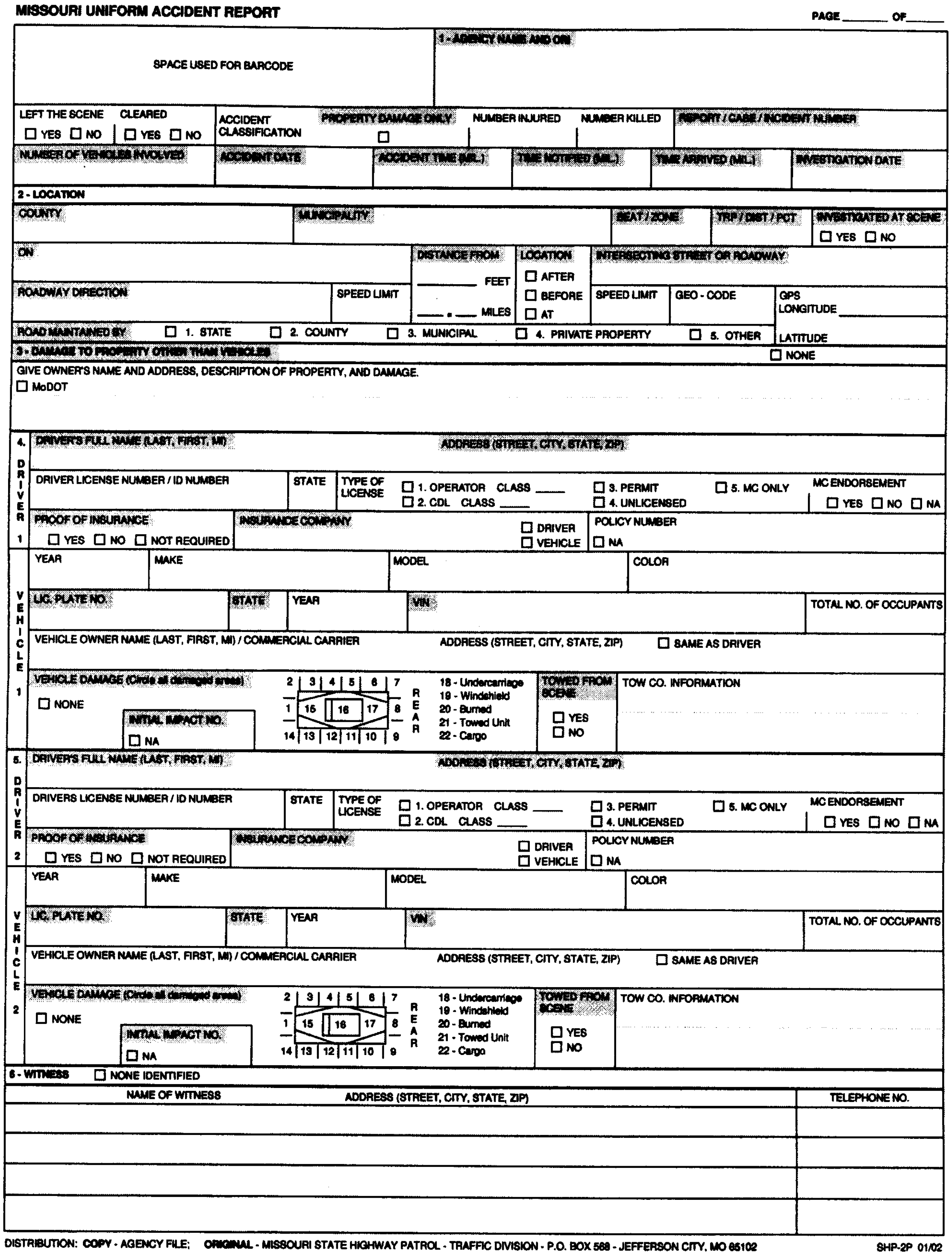
APPENDIX

Missouri Uniform Accident Report Form



MISSOURI UNIFORM ACCIDENT REPORT

PAGE ______ OF ______

SPACE USED FOR BARCODE

1 - AGENCY NAME AND ORI

LEFT THE SCENE ☐ YES ☐ NO

CLEARED ☐ YES ☐ NO

ACCIDENT CLASSIFICATION

PROPERTY DAMAGE ONLY ☐

NUMBER INJURED

NUMBER KILLED

REPORT / CASE / INCIDENT NUMBER

NUMBER OF VEHICLES INVOLVED

ACCIDENT DATE

ACCIDENT TIME (MIL.)

TIME NOTIFIED (MIL.)

TIME ARRIVED (MIL.)

INVESTIGATION DATE

2 - LOCATION

COUNTY

MUNICIPALITY

BEAT / ZONE

TRP / DIST / PCT

INVESTIGATED AT SCENE ☐ YES ☐ NO

ON

DISTANCE FROM ______ FEET ___ . ___ MILES

LOCATION ☐ AFTER ☐ BEFORE ☐ AT

INTERSECTING STREET OR ROADWAY

ROADWAY DIRECTION

SPEED LIMIT

SPEED LIMIT

GEO - CODE

GPS LONGITUDE ______

LATITUDE

ROAD MAINTAINED BY ☐ 1. STATE ☐ 2. COUNTY ☐ 3. MUNICIPAL ☐ 4. PRIVATE PROPERTY ☐ 5. OTHER

3 - DAMAGE TO PROPERTY OTHER THAN VEHICLES ☐ NONE

GIVE OWNER'S NAME AND ADDRESS, DESCRIPTION OF PROPERTY, AND DAMAGE.

☐ MoDOT

4. DRIVER 1

DRIVER'S FULL NAME (LAST, FIRST, MI)

ADDRESS (STREET, CITY, STATE, ZIP)

DRIVER LICENSE NUMBER / ID NUMBER

STATE

TYPE OF LICENSE ☐ 1. OPERATOR CLASS ____ ☐ 2. CDL CLASS ____ ☐ 3. PERMIT ☐ 4. UNLICENSED ☐ 5. MC ONLY

MC ENDORSEMENT ☐ YES ☐ NO ☐ NA

PROOF OF INSURANCE ☐ YES ☐ NO ☐ NOT REQUIRED

INSURANCE COMPANY ☐ DRIVER ☐ VEHICLE

POLICY NUMBER ☐ NA

VEHICLE 1

YEAR

MAKE

MODEL

COLOR

LIC. PLATE NO.

STATE

YEAR

VIN

TOTAL NO. OF OCCUPANTS

VEHICLE OWNER NAME (LAST, FIRST, MI) / COMMERCIAL CARRIER

ADDRESS (STREET, CITY, STATE, ZIP) ☐ SAME AS DRIVER

VEHICLE DAMAGE (Circle all damaged areas) ☐ NONE

INITIAL IMPACT NO. ☐ NA

2 3 4 5 6 7

1 15 16 17 8

14 13 12 11 10 9

REAR

18 - Undercarriage
19 - Windshield
20 - Burned
21 - Towed Unit
22 - Cargo

TOWED FROM SCENE ☐ YES ☐ NO

TOW CO. INFORMATION

5. DRIVER 2

DRIVER'S FULL NAME (LAST, FIRST, MI)

ADDRESS (STREET, CITY, STATE, ZIP)

DRIVERS LICENSE NUMBER / ID NUMBER

STATE

TYPE OF LICENSE ☐ 1. OPERATOR CLASS ____ ☐ 2. CDL CLASS ____ ☐ 3. PERMIT ☐ 4. UNLICENSED ☐ 5. MC ONLY

MC ENDORSEMENT ☐ YES ☐ NO ☐ NA

PROOF OF INSURANCE ☐ YES ☐ NO ☐ NOT REQUIRED

INSURANCE COMPANY ☐ DRIVER ☐ VEHICLE

POLICY NUMBER ☐ NA

VEHICLE 2

YEAR

MAKE

MODEL

COLOR

LIC. PLATE NO.

STATE

YEAR

VIN

TOTAL NO. OF OCCUPANTS

VEHICLE OWNER NAME (LAST, FIRST, MI) / COMMERCIAL CARRIER

ADDRESS (STREET, CITY, STATE, ZIP) ☐ SAME AS DRIVER

VEHICLE DAMAGE (Circle all damaged areas) ☐ NONE

INITIAL IMPACT NO. ☐ NA

2 3 4 5 6 7

1 15 16 17 8

14 13 12 11 10 9

REAR

18 - Undercarriage
19 - Windshield
20 - Burned
21 - Towed Unit
22 - Cargo

TOWED FROM SCENE ☐ YES ☐ NO

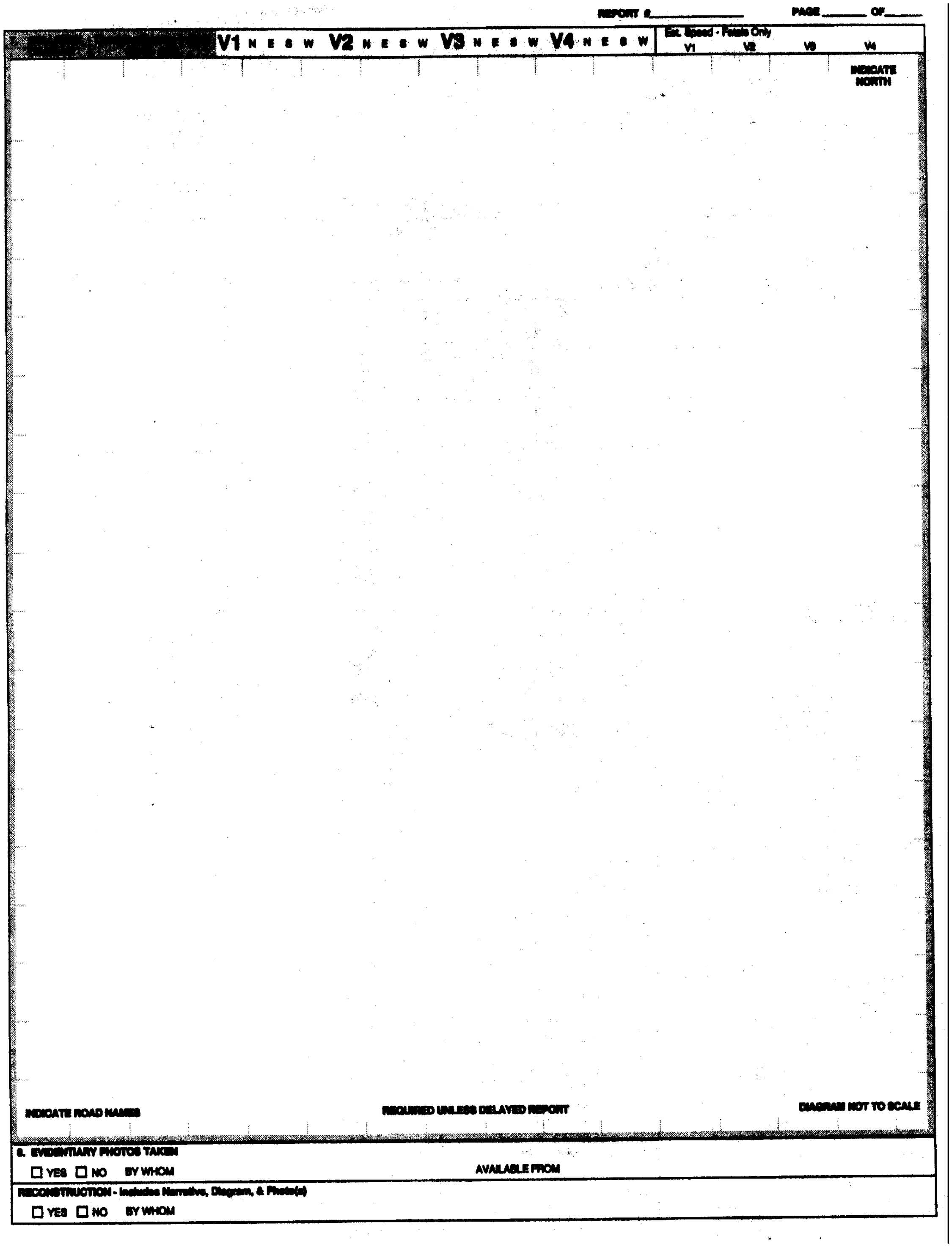
TOW CO. INFORMATION

6 - WITNESS ☐ NONE IDENTIFIED

NAME OF WITNESS	ADDRESS (STREET, CITY, STATE, ZIP)	TELEPHONE NO.

DISTRIBUTION: COPY - AGENCY FILE; ORIGINAL - MISSOURI STATE HIGHWAY PATROL - TRAFFIC DIVISION - P.O. BOX 568 - JEFFERSON CITY, MO 65102

SHP-2P 01/02



REPORT #______________ PAGE ______ OF______

V1 N E S W **V2** N E S W **V3** N E S W **V4** N E S W

Est. Speed - Fatals Only

V1 V2 V3 V4

INDICATE NORTH

INDICATE ROAD NAMES

REQUIRED UNLESS DELAYED REPORT

DIAGRAM NOT TO SCALE

8. EVIDENTIARY PHOTOS TAKEN

☐ YES ☐ NO BY WHOM AVAILABLE FROM

RECONSTRUCTION - Includes Narrative, Diagram, & Photo(s)

☐ YES ☐ NO BY WHOM

REPORT #____________ PAGE ______ OF______

9 - CODES

SEAT LOCATION

XX - Not Known
P - Pedestrian
B - Bicycle
M - Motorcycle
OE - Occupant - Enclosed Load Area
OU - Occupant - Unenclosed Load Area
CP - Commercial Passenger
SV - Other (Explain in Remarks)

FR	SR	TR
FC	SC	TC
FL	SL	TL

INJURY

1. Fatal
2. Disabling
3. Evident - Not Disabling
4. Probable - Not Apparent
5. None Apparent
6. Unknown

TRANSPORTED (Medical Treatment)

1. No
2. EMS
3. Other
4. Unknown

EJECTION

1. NA
2. No
3. Partially
4. Totally
5. Unknown

AIR BAG FRONT

1. None / NA
2. Deployed
3. Not Deployed

AIR BAG SIDE

1. None / NA
2. Deployed
3. Not Deployed

SAFETY DEVICES

1. None
2. Not Used
3. Shoulder Belt Only
4. Lap Belt Only
5. Shoulder and Lap Belt
6. Child Restraint
7. Helmet Used
8. Helmet Not Used
9. Use Unknown

10 - DRIVERS

NAME ADDRESS	DATE OF BIRTH MM-DD-YYYY	SEX	VEH. NO.	SEAT LOC.	INJ.	TRANS-PORT	EJEC-TION	AIR BAG F	AIR BAG S	SAF DEV	TELEPHONE NO.
☐ NA DRIVER 1 - SAME ADDRESS AS ABOVE			1								
☐ NA DRIVER 2 - SAME ADDRESS AS ABOVE			2								

11 - OTHER OCCUPANTS & PEDESTRIANS (SAD = SAME AS DRIVER)

☐ SAD											
☐ SAD											
☐ SAD											
☐ SAD											
☐ SAD											
☐ SAD											

12. VEHICLE BODY TYPES
AUTOMOBILES / SPECIAL VEHICLES

V1 V2
☐ ☐ 1. Passenger Car
☐ ☐ 2. Station Wagon
☐ ☐ 3. Sport Utility Vehicle
☐ ☐ 4. Limousine (9-15 for hire)
☐ ☐ 5. Van (8 or less with driver)
☐ ☐ 6. Small Bus (9-15 with driver)
☐ ☐ 7. Bus (16 or more with driver)
☐ ☐ 8. School Bus (less than 16 with driver)
☐ ☐ 9. School Bus (16 or more with driver)
☐ ☐ 10. Motorcycle
☐ ☐ 11. ATV
☐ ☐ 2 Wh.
☐ ☐ 3 Wh.
☐ ☐ 4 Wh.
☐ ☐ 5 Wh. or More
☐ ☐ Unknown
☐ ☐ 12. Motorized Bicycle
☐ ☐ 13. Pedalcycle
☐ ☐ 14. Motor Home / Camper
☐ ☐ 15. Farm Implements
☐ ☐ 16. Construction Equipment
☐ ☐ 17. Other Transport Device
☐ ☐ 18. Unknown
☐ ☐ 19. Pick-up
☐ ☐ 20. Single-unit Truck: 2 axles, 6 tires
☐ ☐ 21. Single-unit Truck: 3 or more axles

☐ ☐ A. Vehicle Pulling Another Unit(s) 1-21 only

☐ ☐ 22. Truck Tractor With No Units
☐ ☐ 23. Truck Tractor With One Unit
☐ ☐ 24. Truck Tractor With Two Units
☐ ☐ 25. Truck Tractor With Three Units
☐ ☐ 26. Other Heavy Truck

GCVW Rating (not licensed weight) 19-26 only
☐ ☐ Less than or equal to 10,000 lbs.
☐ ☐ 10,001 - 26,000 lbs.
☐ ☐ Greater than 26,000 lbs.

13. EMERGENCY VEHICLE INVOLVEMENT ☐ NA

V1 V2
☐ ☐ 1. Police
☐ ☐ 2. Fire
☐ ☐ 3. Ambulance
☐ ☐ 4. Other (must check "A")

☐ ☐ A. Emergency Vehicle on Emergency Run

14. HAZARDOUS MATERIALS ☐ NA

V1 V2
☐ ☐ Placard Displayed

☐ ☐ 1. Gases in Bulk
☐ ☐ 2. Solids in Bulk
☐ ☐ 3. Liquids in Bulk
☐ ☐ 4. Explosives
☐ ☐ 5. None

☐ ☐ A. Hazardous Materials' Cargo Released / Spilled

15. ACCIDENT TYPE

☐ 1. On Roadway
☐ 2. Off Roadway

COLLISION INVOLVING
☐ 1. Animal
☐ 2. Pedalcycle
☐ 3. Fixed Object
☐ 4. Other Object
☐ 5. Pedestrian
☐ 6. Train
☐ 7. MV in Transport
☐ 8. MV on Other Roadway
☐ 9. Parked MV

NON-COLLISION
☐ 10. Overturning
☐ 11. Other Non-Collision

TWO VEHICLE COLLISION
☐ 60. Head On
☐ 61. Rear End
☐ 62. Sideswipe - Meeting
☐ 63. Sideswipe - Passing
☐ 64. Angle
☐ 65. Backed Into
☐ 67. Other

16. TRAFFIC CONDITIONS

V1 V2
☐ ☐ 1. Normal
☐ ☐ 2. Accident Ahead
☐ ☐ 3. Congestion Ahead

17. VEHICLE ACTION / SEQUENCE OF EVENTS

1. Going Straight
2. Overtaking
3. Making Right Turn
4. Right Turn on Red
5. Making Left Turn
6. Making U Turn
7. Skidding / Sliding
8. Slowing / Stopping
9. Start in Traffic
10. Start From Parked
11. Backing
12. Stopped in Traffic
13. Parked
14. Changing Lanes
15. Avoiding
16. Crossover Median
17. Crossover Centerline
18. Crossing Road
19. Airborne
20. Ran Off Road - Right
21. Ran Off Road - Left
22. Overturn / Rollover
23. Fire / Explosion
24. Immersion
25. Jackknife
26. Cargo Loss / Shift
27. Equipment Failure
28. Separation of Units
29. Returned to Road
30. Collision Inv. Pedestrian
31. Collision Inv. Pedalcycle
32. Collision Inv. Train
33. Collision Inv. Animal (enter code - explain)
34. Collision Inv. MV in Transport
35. Collision Inv. Parked Motor Vehicle
36. Collision Inv. Fixed Object (enter code - explain)
37. Collision Inv. Other Object (explain)
38. Other - Non Collision

V1 ☐ Unknown

______/______/______/______/______/______/______

33. Animal Code ______

36. Fixed Object Code ______/______/______

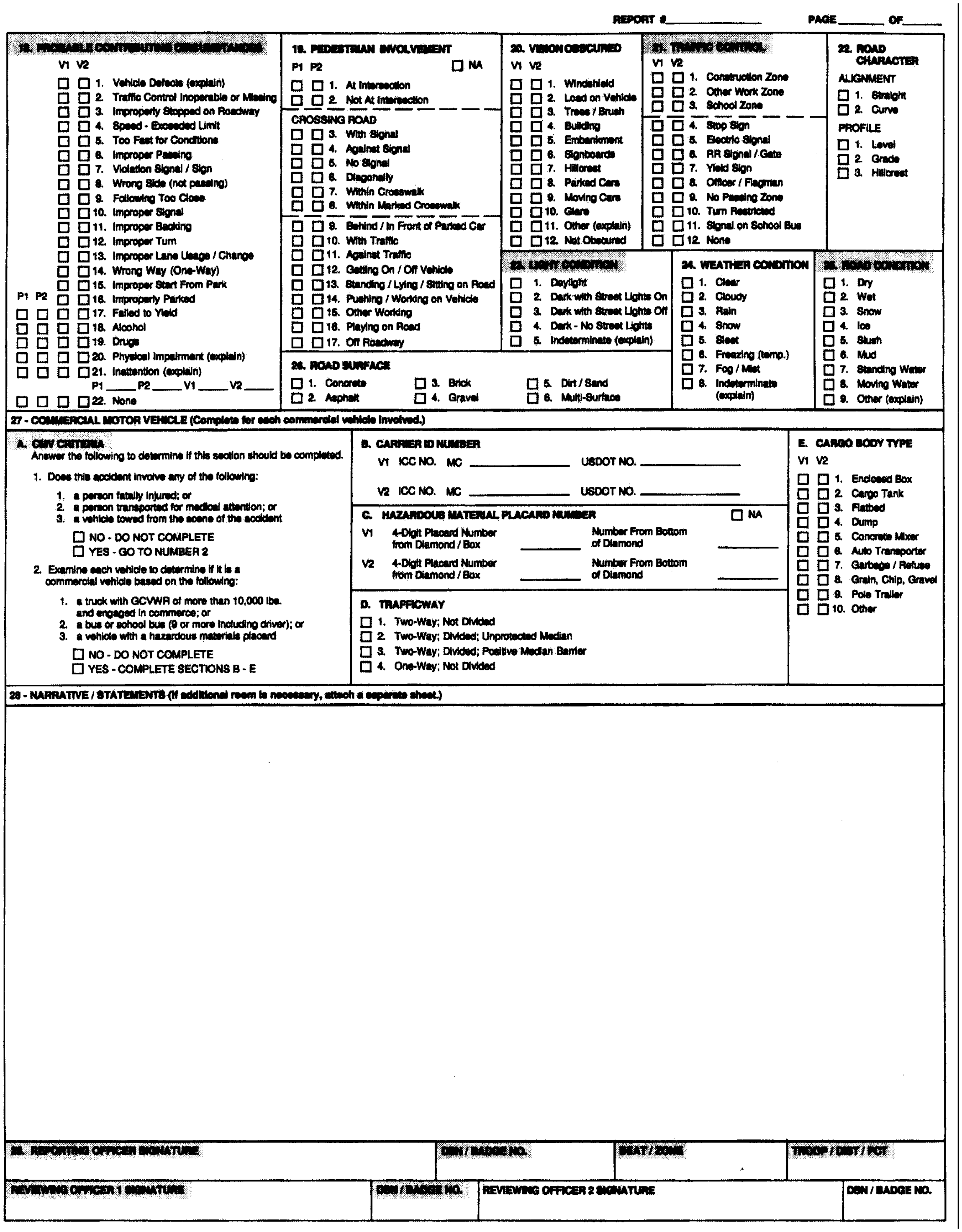
V2 ☐ Unknown

______/______/______/______/______/______/______

33. Animal Code ______

36. Fixed Object Code ______/______/______

Animal, Fixed Object, and Inattention Codes explained in narrative.



REPORT #______________ PAGE ________ OF______

18. PROBABLE CONTRIBUTING CIRCUMSTANCES

V1 V2

☐ ☐ 1. Vehicle Defects (explain)
☐ ☐ 2. Traffic Control Inoperable or Missing
☐ ☐ 3. Improperly Stopped on Roadway
☐ ☐ 4. Speed - Exceeded Limit
☐ ☐ 5. Too Fast for Conditions
☐ ☐ 6. Improper Passing
☐ ☐ 7. Violation Signal / Sign
☐ ☐ 8. Wrong Side (not passing)
☐ ☐ 9. Following Too Close
☐ ☐ 10. Improper Signal
☐ ☐ 11. Improper Backing
☐ ☐ 12. Improper Turn
☐ ☐ 13. Improper Lane Usage / Change
☐ ☐ 14. Wrong Way (One-Way)
☐ ☐ 15. Improper Start From Park
☐ ☐ 16. Improperly Parked

P1 P2

☐ ☐ ☐ ☐ 17. Failed to Yield
☐ ☐ ☐ ☐ 18. Alcohol
☐ ☐ ☐ ☐ 19. Drugs
☐ ☐ ☐ ☐ 20. Physical Impairment (explain)
☐ ☐ ☐ ☐ 21. Inattention (explain)
P1 _____ P2 _____ V1 _____ V2 _____
☐ ☐ ☐ ☐ 22. None

19. PEDESTRIAN INVOLVEMENT

P1 P2 ☐ NA

☐ ☐ 1. At Intersection
☐ ☐ 2. Not At Intersection

CROSSING ROAD

☐ ☐ 3. With Signal
☐ ☐ 4. Against Signal
☐ ☐ 5. No Signal
☐ ☐ 6. Diagonally
☐ ☐ 7. Within Crosswalk
☐ ☐ 8. Within Marked Crosswalk

☐ ☐ 9. Behind / In Front of Parked Car
☐ ☐ 10. With Traffic
☐ ☐ 11. Against Traffic
☐ ☐ 12. Getting On / Off Vehicle
☐ ☐ 13. Standing / Lying / Sitting on Road
☐ ☐ 14. Pushing / Working on Vehicle
☐ ☐ 15. Other Working
☐ ☐ 16. Playing on Road
☐ ☐ 17. Off Roadway

20. VISION OBSCURED

V1 V2

☐ ☐ 1. Windshield
☐ ☐ 2. Load on Vehicle
☐ ☐ 3. Trees / Brush
☐ ☐ 4. Building
☐ ☐ 5. Embankment
☐ ☐ 6. Signboards
☐ ☐ 7. Hillcrest
☐ ☐ 8. Parked Cars
☐ ☐ 9. Moving Cars
☐ ☐ 10. Glare
☐ ☐ 11. Other (explain)
☐ ☐ 12. Not Obscured

21. TRAFFIC CONTROL

V1 V2

☐ ☐ 1. Construction Zone
☐ ☐ 2. Other Work Zone
☐ ☐ 3. School Zone

☐ ☐ 4. Stop Sign
☐ ☐ 5. Electric Signal
☐ ☐ 6. RR Signal / Gate
☐ ☐ 7. Yield Sign
☐ ☐ 8. Officer / Flagman
☐ ☐ 9. No Passing Zone
☐ ☐ 10. Turn Restricted
☐ ☐ 11. Signal on School Bus
☐ ☐ 12. None

22. ROAD CHARACTER

ALIGNMENT

☐ 1. Straight
☐ 2. Curve

PROFILE

☐ 1. Level
☐ 2. Grade
☐ 3. Hillcrest

23. LIGHT CONDITION

☐ 1. Daylight
☐ 2. Dark with Street Lights On
☐ 3. Dark with Street Lights Off
☐ 4. Dark - No Street Lights
☐ 5. Indeterminate (explain)

24. WEATHER CONDITION

☐ 1. Clear
☐ 2. Cloudy
☐ 3. Rain
☐ 4. Snow
☐ 5. Sleet
☐ 6. Freezing (temp.)
☐ 7. Fog / Mist
☐ 8. Indeterminate (explain)

25. ROAD CONDITION

☐ 1. Dry
☐ 2. Wet
☐ 3. Snow
☐ 4. Ice
☐ 5. Slush
☐ 6. Mud
☐ 7. Standing Water
☐ 8. Moving Water
☐ 9. Other (explain)

26. ROAD SURFACE

☐ 1. Concrete
☐ 2. Asphalt
☐ 3. Brick
☐ 4. Gravel
☐ 5. Dirt / Sand
☐ 6. Multi-Surface

27 - COMMERCIAL MOTOR VEHICLE (Complete for each commercial vehicle involved.)

A. CMV CRITERIA

Answer the following to determine if this section should be completed.

1. Does this accident involve any of the following:
   1. a person fatally injured; or
   2. a person transported for medical attention; or
   3. a vehicle towed from the scene of the accident

   ☐ NO - DO NOT COMPLETE
   ☐ YES - GO TO NUMBER 2
2. Examine each vehicle to determine if it is a commercial vehicle based on the following:
   1. a truck with GCVWR of more than 10,000 lbs. and engaged in commerce; or
   2. a bus or school bus (9 or more including driver); or
   3. a vehicle with a hazardous materials placard

   ☐ NO - DO NOT COMPLETE
   ☐ YES - COMPLETE SECTIONS B - E

B. CARRIER ID NUMBER

V1 ICC NO. MC ______________ USDOT NO. ______________

V2 ICC NO. MC ______________ USDOT NO. ______________

C. HAZARDOUS MATERIAL PLACARD NUMBER ☐ NA

V1 4-Digit Placard Number from Diamond / Box ________ Number From Bottom of Diamond ________

V2 4-Digit Placard Number from Diamond / Box ________ Number From Bottom of Diamond ________

D. TRAFFICWAY

☐ 1. Two-Way; Not Divided
☐ 2. Two-Way; Divided; Unprotected Median
☐ 3. Two-Way; Divided; Positive Median Barrier
☐ 4. One-Way; Not Divided

E. CARGO BODY TYPE

V1 V2

☐ ☐ 1. Enclosed Box
☐ ☐ 2. Cargo Tank
☐ ☐ 3. Flatbed
☐ ☐ 4. Dump
☐ ☐ 5. Concrete Mixer
☐ ☐ 6. Auto Transporter
☐ ☐ 7. Garbage / Refuse
☐ ☐ 8. Grain, Chip, Gravel
☐ ☐ 9. Pole Trailer
☐ ☐ 10. Other

28 - NARRATIVE / STATEMENTS (If additional room is necessary, attach a separate sheet.)

29. REPORTING OFFICER SIGNATURE	DSN / BADGE NO.	BEAT / ZONE	TROOP / DIST / PCT
REVIEWING OFFICER 1 SIGNATURE	DSN / BADGE NO.	REVIEWING OFFICER 2 SIGNATURE	DSN / BADGE NO.

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 Passeger 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,drvrID,vehBodyTypeNum,vehBodyType,contribCode,contrib2Fault,atFault,contribCircum,
rdAlign,rdProfile,lightCond,weatherCond,rdCond,dup_accNum,dup_tdate,dup_hwyClass,dup_locSt,distFeet,distMile,intrsecLoc,cross
Street,twyId,twyName,dir,log]=textread(file_name,'%n%s%s%s%s%n%n%s%s%s%s%s%s%s%s%s%n%s%s%s%n%f%s%s%n
%n%s%f%*[^\n]','delimiter','\t','headerlines',1);

                    % Column 9 which is Contibuting 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 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);
```

Safety Corridor Contacts

State	Safety Corridor Contact Name (Agency)
Alaska	Scott Thomas (Alaska DOT&PF)
California	Ophelia Torpey (California Highway Patrol)
	Ken Kochevar (FHWA, California Division)
Florida	Peter Hsu (Florida DOT)
Kentucky	Boyd Sigler (Kentucky Transportation Cabinet)
Minnesota	Sue Groth (Minnesota DOT)
	Dave Engstrom (Minnesota DOT)
	Dave Kopacz (FHWA, Minnesota Division)
New Jersey	Kevin Conover (New Jersey DOT)
	Karen Yunk (FHWA, New Jersey Division)
New Mexico	Mike Quintana (New Mexico DOT)
	Alan Ho (FHWA, New Mexico Division)
New York	Barbara O'Rourke (New York DOT)
	Jim Growney (FHWA, New York Division)
Ohio	Michelle May (Ohio DOT)
	Joe Glinski (FHWA, Ohio Division)
Oregon	Anne Holder (Oregon DOT)
	KC Humphrey (Oregon DOT, Region 1)
	Nick Fortey (FHWA, Oregon Divison)
Pennsylvania	Gary Modi (Pennsylvania DOT)
	Michael Castellano (FHWA, Pennsylvania Division)
Virginia	Stephen Read (Virginia DOT)
	Becky Crowe (FHWA, Virginia Division)
Washington	Matthew Enders (Washington DOT)
	Chad Hancock (Washington DOT, Southwest Region)
	John Manix (City of Vancouver, Washington)
	Don Peterson (FHWA, Washington Division)

Alaska Safety Corridor Legislation

Section 2B.17 FINES HIGHER Plaque (R2-6)

Add the following at the end of the section:

Safety Zone Signing.

Support:

The BEGIN HIGHWAY SAFETY ZONE TRAFFIC FINES DOUBLE (R16-112) and END DOUBLE TRAFFIC FINES (R16-101) signs legally establish the beginning and end of safety zones.

Safety Zones become effective when the Commissioner of the DOT&PF and Commissioner of the Department of Public Safety sign a Highway Safety Corridor Designation form.

Standard:

Safety zone (corridor) signing in accordance with AS 19.10.075 shall only be installed on rural roads that meet the following conditions:

1. Are designated as either
   a. an Interstate, or
   b. a rural major arterial, or
   c. a rural major collector with 2000 ADT or more, or
   d. a rural minor arterial with 2000 ADT or more.
2. Have a three-year fatal+major injury incident rate per mile that exceeds 110% of the statewide average for rural arterials.
3. Have a three-year fatal+major injury crash rate per 100 million vehicle miles that exceeds 110% of the statewide average for rural arterials.
4. The DOT&PF and the police agency with jurisdiction agree on a coordinated traffic control / traffic patrol plan.
5. DOT&PF and the police agree the proposed safety zone will be effective in reducing highway crashes.
6. The police agency with jurisdiction agrees to define the amount of enforcement needed to increase safe driver behavior in the safety zone, and to provide that enforcement on an ongoing basis.

No more than ten safety zones shall exist in Alaska at one time.

Option.

The DOTPF may choose not to sign all road segments that meet the above criteria.

Periods longer than three years (up to 5 years) may be used for incident and injury rates used for establishing safety zones.

Support.

The two accident rates serve different purposes. The per-mile injury rate indicates crash concentration while the per-vehicle mile crash rate is an indication of correctability. If both thresholds are exceeded, safety countermeasures can be expected to significantly reduce crashes.

Guidance.

Safety zones should include road segments of similar character and begin and end at logical locations. If a short non-qualifying segment exists between two qualifying segments, consider extending the zone across the non-qualifying segment. Zones should be no shorter than 5 miles.

Standard.

Safety zone signs shall be removed when the fatal + major injury rate per mile falls below the statewide average for a three year period.

Option.

Safety zone signs may be removed sooner if the DOT&PF and police agency with jurisdiction agree the safety zone is no longer effective or conditions have changed in a way that makes the safety zone unnecessary.

Standard.

BEGIN HIGHWAY SAFETY ZONE TRAFFIC FINES DOUBLE (R16-112) signs and SAFETY ZONE SPEED LIMIT (R2-101) signs shall be posted at the beginning of every safety zone, in that order.

END DOUBLE FINES (R16-101) signs shall be posted at the end of every safety zone.

All existing regulatory speed limit signs within the double fines zone shall either be replaced with SAFETY ZONE SPEED LIMIT (R2-101) signs or supplemented with SAFETY ZONE (R16-114) plates.

When a double fine zone is longer than 3 miles, SAFETY ZONE SPEED LIMIT (R2-101) signs or standard SPEED LIMIT (R2-1) signs with SAFETY ZONE (R16-114) plates shall be posted at spacings not greater than 3 miles (+/- ½ mile) within the safety zone.

SAFETY ZONE SPEED LIMIT (R2-101) signs or standard SPEED LIMIT (R2-1) signs with SAFETY ZONE (R16-114) plates shall be installed on the main street on either side of major intersections within safety zone.

Install either SAFETY ZONE BEGIN DOUBLE TRAFFIC FINES (R16-113) or BEGIN HIGHWAY SAFETY ZONE TRAFFIC FINES DOUBLE (R16-112) signs on side streets entering the safety zone. These signs are only required on side streets functionally classified as collector or higher.