INTERSTATE HIGHWAY SAFETY STUDY

ANALYSIS OF VEHICLE CRASHES RELATED TO SAFETY REST AREA SPACING

Prepared For:

Minnesota Department of Transportation
Office of Technical Support

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Highway Safety Study: Analysis of Vehicle Crashes Related to Safety Rest Area Spacing

1.0 Study Summary

1.1 Study Purpose

The Minnesota Department of Transportation (Mn/DOT) desired to replicate a study originally undertaken by Michigan State University, as published in 2000 in a paper entitled, *"A Study of Highway Rest Areas and Fatigue-Related Truck Crashes"* by William C. Taylor and Nakmoon Sung. The Michigan study analyzed the relationship between safety rest area spacing on Michigan interstate highways and vehicle crashes and concluded that there was a positive relationship between safety rest area spacing and fatigue-related single-vehicle truck crashes. Specifically, it was demonstrated that freeway segments 30 miles or more beyond a safety rest area experienced disproportionately more single-vehicle truck crashes than segments less than 30 miles from a safety rest area. Researchers designed the Mn/DOT study to replicate the methodology of the Taylor and Sung study, using Minnesota data and conditions to study the relationship between interstate highway crashes and safety rest area spacing and other potential influencing factors on interstate highway safety. The Mn/DOT study included an additional analysis conducted to determine if a relationship exists between Commercial Motor Vehicle (CMV) nighttime parking demand in safety rest areas and interstate highway accidents.

1.2 Methodology

This study relied on Minnesota's accident record database, as recorded by the Minnesota Department of Public Safety (DPS) and Mn/DOT for the 10-year time period from 1995 through 2004. Researchers also used additional data including average annual daily traffic (AADT), heavy commercial average daily traffic (HCADT), hourly traffic volumes from Mn/DOT's system of automated traffic recorders (ATRs) located around the state, and 10 years of nighttime safety rest area CMV parking demand data. Data was summarized and displayed in data plots to identify trends and patterns, and statistical tests were performed to identify cases where these trends illustrated statistically significant results. Normalization was also used to compute crash rates, which allowed researchers and the study team to compare crash characteristics on roadways with different traffic volumes or exposure levels.

1.3 Key Findings

- There is a relationship between safety rest area spacing and single-vehicle truck crashes during all times of the day.
- There is a relationship between high safety rest area nighttime vehicle percent of parking capacity filled and high downstream nighttime single-vehicle truck crashes.
- Statistical tests conducted indicated that the nighttime percent of parking capacity filled for safety rest areas had good predictive capabilities for nighttime single-vehicle truck crashes.

1.4 Conclusions

The study found that there is a direct relationship between safety rest area spacing and single-vehicle truck crashes during all times of the day. In addition, the study found a relationship between high levels of CMV parking capacity filled and the incidence of nighttime single-vehicle truck crashes.

One key difference between the Minnesota study and the Taylor and Sung study in Michigan is that researchers discovered a relationship between safety rest area spacing and the incidence of nighttime single-vehicle truck crashes in Michigan. Researchers could not replicate this finding in the Minnesota study (see discussion in Sections 3.2.7 and 4.1). Researchers believe that the Minnesota study could not replicate the Michigan findings because Minnesota safety rest area spacing seldom exceeds 50 miles. Specifically, only six of the 34 safety rest areas in this sample exceeded 50 mile spacing, with only one of the 34 safety rest areas being spaced more than 60 miles apart.

Researchers believe Mn/DOT may draw a policy inference from these findings. First, Minnesota safety rest area spacing is adequate. Second, nighttime CMV parking demand on Minnesota interstate highways may contribute to a safety issue. Third, research should define actions to take based on these findings, including conducting benefit-cost analyses and other policy analysis investigations to help Mn/DOT set investment priorities.

2.0 Study Background

Mn/DOT constructs safety rest areas along interstate highways to provide motorists with a safe location to pull over and rest. Tired drivers are dangerous drivers, and the size of most commercial trucks in relation to automobiles increases the severity of any crashes that may result. A 1998 U.S. Department of Transportation (DOT) report (*Trends in Large Truck Crashes)* stated that "large trucks account for about 3.5 percent of all vehicles and for approximately 7 percent of all vehicle travel, while accounting for at least 12 percent of all traffic fatalities." Further research by the National Highway Traffic Safety Administration (NHTSA) suggests that truck driver fatigue may be a contributing factor in as many as 30 to 40 percent of all heavy truck accidents and that 31 percent of accidents fatal to truck drivers are fatigue related.

Mn/DOT has conducted and continues to conduct various studies and data collection efforts to define the role that Minnesota safety rest areas play on the state's system of interstate highways. Studies include conducting periodic onsite daytime motorist usage surveys, collecting and analyzing nighttime parking demand at safety rest areas, identifying high-use nighttime truck parking locations and developing future parking demand projections and recommendations for meeting demand. Since 1995, Mn/DOT has collected and continues to collect nighttime vehicle parking counts. Custodial staff collect data three times nightly at all interstate rest areas. This nighttime-use information is maintained by the Site Development Unit in a database. These background efforts helped to lay the groundwork and provide the foundation for the current research initiative.

2.1 Study Objectives

The Taylor and Sung study of interstate highway miles in Michigan documented an analysis that found a relationship relating crashes to safety rest area spacing. The Michigan study determined that there was a relationship between safety rest area spacing and nighttime single-vehicle truck crashes and, furthermore, that the probability for a crash increased when safety rest area spacing exceeded 30 miles.

Mn/DOT asked researchers to replicate the methodology of the Taylor and Sung study, using Minnesota data and conditions, to study the relationship between interstate highway crashes and safety rest area spacing and other potential influencing factors on interstate highway safety.

2.2 Study Process

Researchers used a two-phase study design for the Minnesota investigation of safety rest area spacing and interstate highway crashes. The first phase included designing the study and testing the design methodology on a 150-mile interstate highway segment. After testing the methodology, researchers refined the methodology to test many factors looking for potential areas of interest. These factors included types of crashes, weather conditions, accident contributing factors (including condition of driver) and other factors that may play a role in crash occurrences. Researchers then applied the refined methodology to all rural Minnesota interstate highway miles.

Mn/DOT assembled an interdisciplinary Technical Advisory Committee (TAC) to oversee the study. The TAC included Mn/DOT planners, engineers and experts in freight, market research, safety and safety rest area development. Mn/DOT staff worked in partnership with their research consultant, SRF Consulting Group, Inc., to conduct this research effort and develop this paper. A list of TAC members is presented in Appendix A.

2.3 Study Methodology

2.3.1 Data Sources

This study relied heavily on Minnesota's accident record database, as recorded by the Minnesota DPS and Mn/DOT. The accident record database contained standardized information on all crashes occurring on Minnesota's interstate highway miles from 1995 through 2004, totaling more than 140,000 records. These records represent a summary of information documented by the traffic safety officer called to the scene, including date and time, location, number of vehicles involved (as well as the types of vehicles) and the number of occupants in each vehicle involved in a crash. Appendix B includes a complete list of data fields and standardized entries in this dataset.

Additional data sources used in this study included average annual daily traffic (AADT), heavy commercial average daily traffic (HCADT) and data from Mn/DOT's system of in-pavement automated traffic recorders (ATRs) located around the state. Additionally, the study used a unique set of nighttime CMV parking data, as recorded by safety rest area staff. In all instances, researchers used data for the 10-year timeframe from 1995 through 2004.

2.3.2. Study Limits

Researchers excluded urban interstate highway segments from the study based on differences between metropolitan-area traffic, specifically heavy-commercial traffic and rural interstate highway traffic. The study therefore excluded Twin Cities metropolitan area interstate highways defined as those within the I-494/I-694 beltways and that portion of I-94 extending from I-694 to the Wisconsin border.

The final study sample included 690 total interstate highway miles within Minnesota consisting of the following:

- I-90 in its entirety
- I-35 in its entirety with the exception of I-35W and I-35E, which lie within the excluded area of the Twin Cities metropolitan area
- I-94 from North Dakota to the western edge of the Twin Cities metropolitan area at its intersection with I-494/I-694

The study sample included a total of 34 safety rest areas located on these interstate highway segments. See Figure 1 for a map of the interstate highways and safety rest areas included in this study.

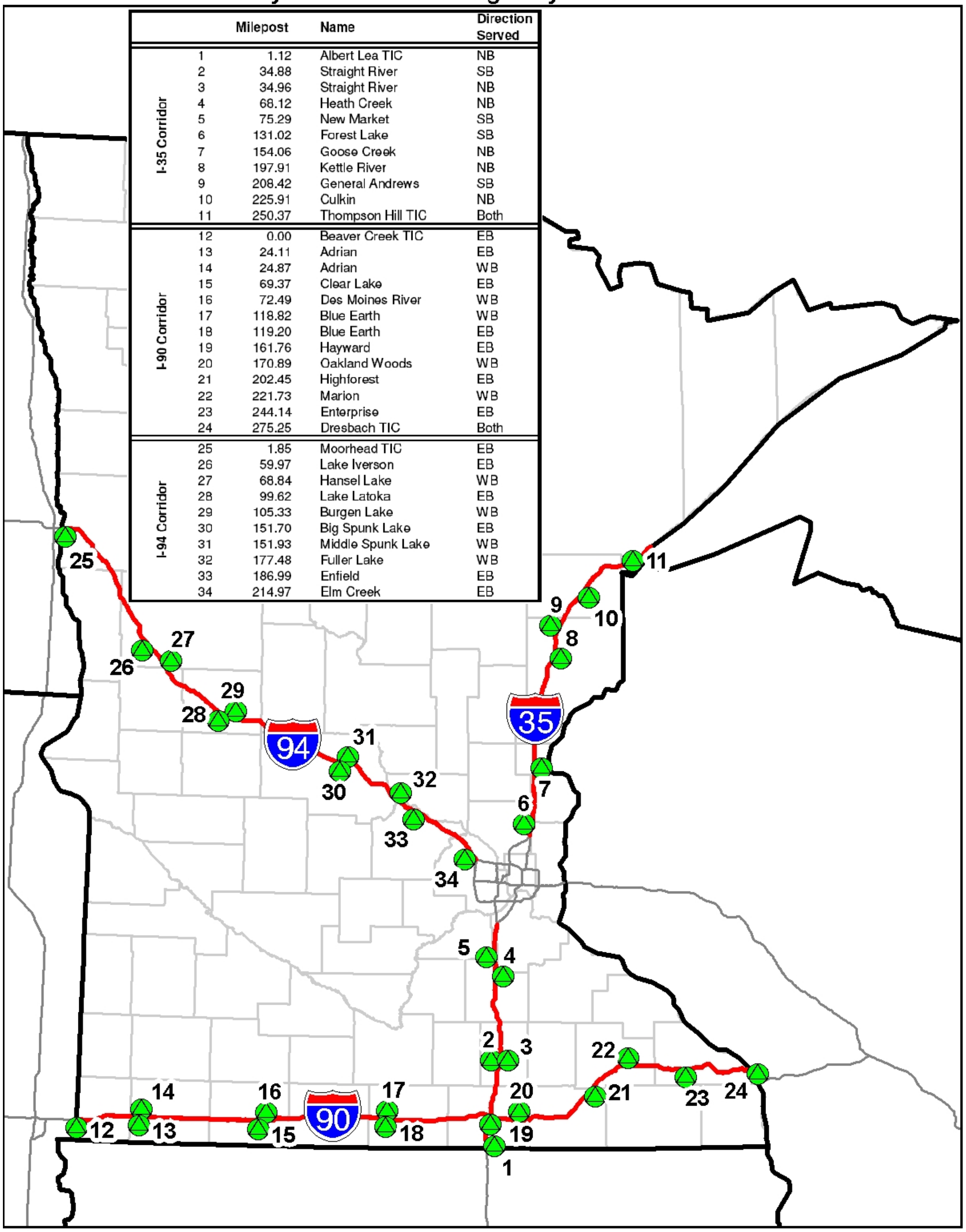
2.3.3 Analysis Tools

2.3.3.1 Data Plots

The crash data were used to analyze the characteristics of crashes occurring on rural Minnesota interstate highways, and a variety of data plotting methods were used to graphically display summaries of the data analysis information. These plots were useful in visually showing the occurrence patterns of crashes by time of day, month of year, physical characteristics of the driver involved and many other attributes. Peaks on these plots helped to identify trends in the data or clusters of crashes that may have occurred at different times and locations. This information was used to make inferences regarding crashes by time of day and month of year.

Figure 1
Study Area Interstate Highways and Rest Areas

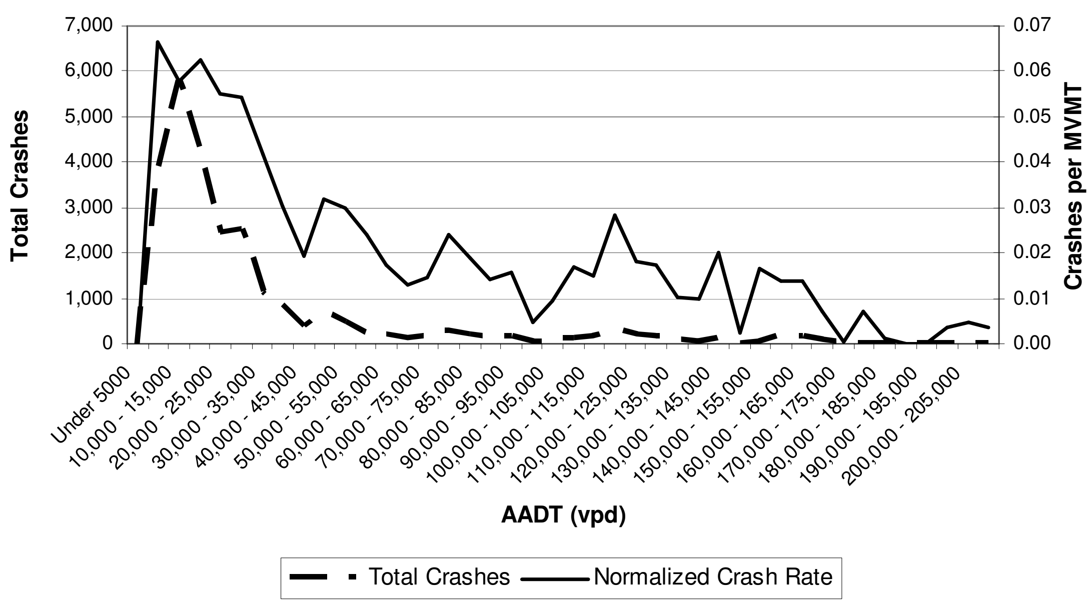
Corridor		Milepost	Name	Direction Served
I-35 Corridor	1	1.12	Albert Lea TIC	NB
	2	34.88	Straight River	SB
	3	34.96	Straight River	NB
	4	68.12	Heath Creek	NB
	5	75.29	New Market	SB
	6	131.02	Forest Lake	SB
	7	154.06	Goose Creek	NB
	8	197.91	Kettle River	NB
	9	208.42	General Andrews	SB
	10	225.91	Culkin	NB
	11	250.37	Thompson Hill TIC	Both
I-90 Corridor	12	0.00	Beaver Creek TIC	EB
	13	24.11	Adrian	EB
	14	24.87	Adrian	WB
	15	69.37	Clear Lake	EB
	16	72.49	Des Moines River	WB
	17	118.82	Blue Earth	WB
	18	119.20	Blue Earth	EB
	19	161.76	Hayward	EB
	20	170.89	Oakland Woods	WB
	21	202.45	Highforest	EB
	22	221.73	Marion	WB
	23	244.14	Enterprise	EB
	24	275.25	Dresbach TIC	Both
I-94 Corridor	25	1.85	Moorhead TIC	EB
	26	59.97	Lake Iverson	EB
	27	68.84	Hansel Lake	WB
	28	99.62	Lake Latoka	EB
	29	105.33	Burgen Lake	WB
	30	151.70	Big Spunk Lake	EB
	31	151.93	Middle Spunk Lake	WB
	32	177.48	Fuller Lake	WB
	33	186.99	Enfield	EB
	34	214.97	Elm Creek	EB



2.3.3.2 Data Normalization

When looking at the influence of certain direct relationships on interstate crashes, normalization of data was required to account for different levels of exposure, thus allowing the underlying characteristics of the data sets to be compared. A large proportion of tests were normalized for exposure to the attribute being considered, including annual average daily traffic (AADT), heavy/commercial average daily traffic (HCADT), and safety rest area CMV parking demand. For example, because the majority of Minnesota interstate highway miles have AADT levels above 10,000 vehicles per day (vpd), there were many more total crashes occurring on high-volume interstate segments compared to low-volume segments. Researchers normalized the data using crash rates and/or exposure to account for variances in traffic volumes and length of segments. Computing the crash rate on each segment enabled comparisons to be made across different traffic volumes. An example of the normalized rate compared to the total crashes is shown below in Figure 2.

Figure 2
Distribution of Crashes and Crash Rate by AADT
All Study Area Interstate Highway Segments, N = 25,427



Note: Some data records were not included due to incomplete attribute data.

2.3.3.3 Statistical Significance

In addition to normalizing the data, the statistical significance of trends was also measured. This was done by establishing the trendline matching the data points. A trendline is a graphical representation of an equation that is estimated to best describe the relationship between the variables being compared. The significance of a trendline is quantified in an R-square value. Therefore, it was appropriate to use in cases where we were looking for indications that changes in values of two variables are related. Establishing a predictive relationship between accident causal factors permits decision makers to use the data to assess the value of alternative accident reduction measures. For example, if a predictive value can be established relating the number of crashes occurring each year on a freeway segment relative to nighttime percent of parking capacity filled levels at safety rest areas, then observed and/or future percent of parking capacity levels may be used to predict the number of crashes that would be anticipated to occur on a freeway segment. This information could be used, in turn, to evaluate the safety effects of adding parking capacity at safety rest areas with high percent of parking capacity levels.

Other estimates of statistical significance, such as standard error, were not widely used in this study. Standard error, which is an estimate of the standard deviation of error in a measurement, was not particularly relevant for a number of reasons. First, the entire population of crash attributes was available in the study instead of a subset or sample group. Second, measures of center and spread were not generally considered in this study, for which estimates of standard error are descriptive. Finally, the data were typically not used in functions to develop new variables where computing the standard error of the new dataset would be required.

2.3.3.4 Data Outliers

An additional element of the analysis process is the treatment of outliers. Outliers describe data points that lie outside the range within which the large majority of most data in a given sample falls. In some cases, these data points are important because they illustrate large variability in the conditions being measured and their presence impacts the results of the analysis. In other cases, outliers may be the consequence of measurement or coding errors or isolated observations that are not relevant to the overall data set.

An example of outliers in this study was crashes occurring 75 miles or more downstream from the previous safety rest area. This subset includes only one freeway segment on the rural interstate mileage that was part of the data set and very few crashes occurred there. Therefore, these crashes were not included in the estimation of trendlines because they are not representative of conditions widely found on Minnesota's rural interstate highways. Outliers were only identified and eliminated in three of the tests in the study.

3.0 Analysis and Results

3.1 Overview

This section contains key findings and summarizes the analysis process and results of the study. Researchers tested a broad sample of data looking for trends illustrating statistical significance. (See Appendix C for a complete list of general tests conducted.) Preliminary findings of interest were further tested for patterns and relationships using a "drilled down" process to explore the significance of findings that were discovered in previous tests. For example, although all crashes were analyzed for some initial study tests, the focus of these efforts quickly turned to crashes involving commercial vehicles and, even further, to single-vehicle truck crashes.

3.2 Key Findings

Key findings regarding the relationship of safety rest areas and interstate freeway crashes are summarized as follows. A complete summary of all tests and resulting products is presented in Appendix D.

3.2.1 Distribution of Truck Crashes and Truck Volumes by Time of Day

Test Purpose/Goal

Researchers performed this test to assess how truck crashes varied by time of day and, specifically, how the distribution of single-truck and multi-truck crashes was either similar or dissimilar. Truck crashes were also compared to volumes of truck traffic by the hour of the day to determine the extent to which truck crash patterns were similar or dissimilar to daily patterns of truck volumes.

The goal of the test was to determine whether single-truck crashes diverged in their pattern from hourly truck volume patterns, similar to the trend found in the Taylor and Sung study.

Test Findings

a. The occurrence of multi-vehicle truck crashes is closely related to the volume of trucks using the highway at the time of the incident.

b. Single-vehicle truck crashes occur at a disproportionate rate to truck volumes during nighttime hours. The hourly percentage of single-vehicle truck crashes begins to exceed hourly truck volume percentages beginning at 10:00 p.m. and continuing until 6:00 a.m.

c. Multi-vehicle truck crashes follow a pattern very closely related to patterns of truck volumes during the course of a day.

d. The pattern of single-vehicle truck crashes during the course of a day is different from the pattern of multi-vehicle truck crashes. Multi-vehicle truck crashes follow the daily patterns of hourly truck volumes, but single-vehicle truck crashes do not and are comparatively constant throughout the day.

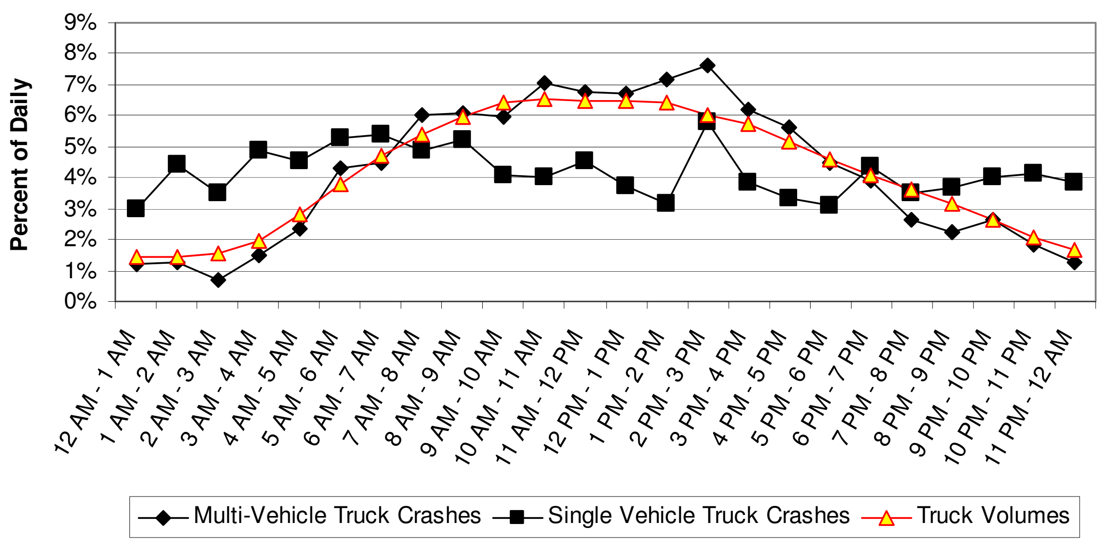
<u>Data/Methodology</u>

a. All data used in this analysis was aggregated on a statewide level.

b. Automated Traffic Recorder (ATR) truck volume data was aggregated for all locations on all days that had complete 24-hour records. The hourly percentages are the sums of each hour of the day for all records divided by the total volume of all hours for all records.

c. The entire statewide sample of rural interstate crashes was used in this analysis. The crash data was separated into single-vehicle truck crashes and multi-vehicle truck crashes. The hourly percentages are the number of crashes occurring during that hour divided by the total number of crashes in the subset.

Figure 3
Distribution of Truck Crashes and Truck Volumes by Time of Day
All Study Area Interstate Highway Segments



Note: Some data records were not included due to incomplete attribute data.

Conclusion

The pattern of single-vehicle truck crashes during the course of a day is different from the pattern of multi-vehicle truck crashes. Multi-vehicle truck crashes follow the daily patterns of hourly truck volumes, but single-vehicle truck crashes do not and are comparatively constant throughout the day. Single-vehicle truck crashes had different peaking characteristics than multi-vehicle truck crashes. Analysis shows that 39 percent of single-truck crashes occur between 10 p.m. and 6 a.m. despite only 21 percent of truck volume occurring during these hours. This is nearly twice as many crashes as the traffic exposure alone would suggest and confirmed a key study conclusion of the earlier Taylor and Sung study. Single-vehicle nighttime truck crashes were used as a proxy for fatigue-related crashes.

3.2.2 Crashes by Day of Week

Test Purpose/Goal

Researchers performed this test to determine overall patterns of the distribution of crashes over the course of a week and whether patterns of truck crashes departed from patterns seen when observing crashes involving all types of vehicles.

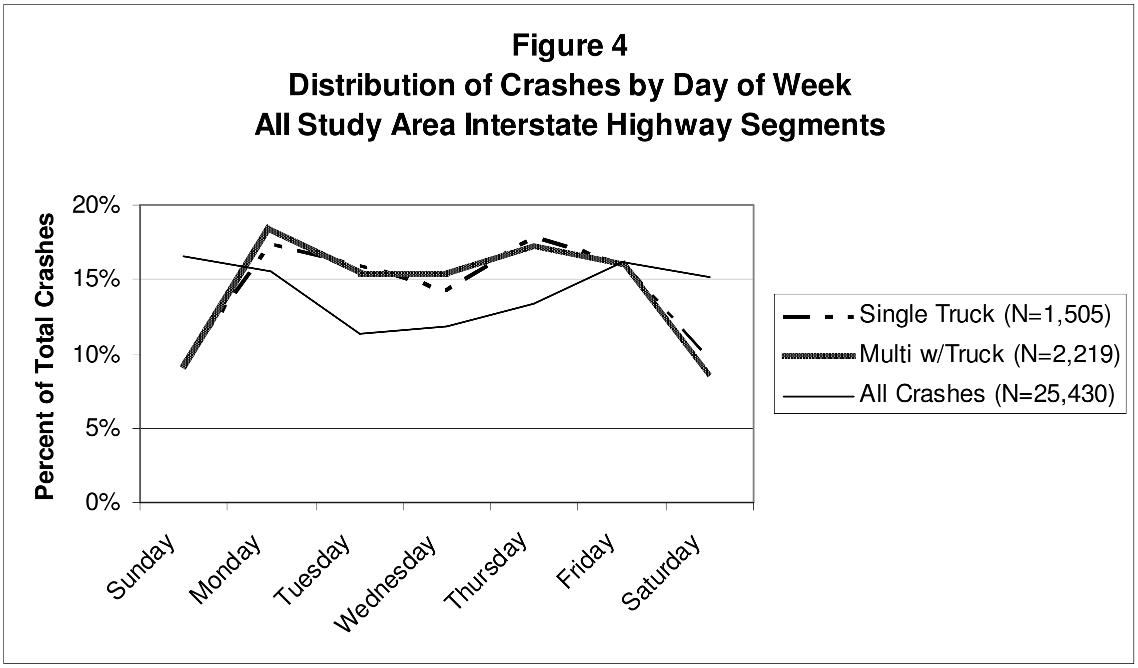
The goal of this test was to look for differences in crash patterns between trucks and all other types of vehicles.

Test Findings

a. Truck crashes are at their highest levels during weekdays, with a peak on Monday and a slightly less distinct peak on Thursday.
b. In contrast, crashes involving all types of vehicles, including passenger cars, light trucks and vans, reach their peak on weekend days, with the highest levels of crashes occurring on Sundays.

Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.
b. The entire statewide sample of 25,430 rural interstate crashes was used in this analysis. The crash data was separated into single-vehicle truck crashes and multi-vehicle truck crashes, and all crashes (including passenger cars, pickups, SUVs, vans, and motorcycles in addition to truck crashes) were also considered.



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. Analysis of multi- and single-vehicle truck crashes by day of week, in comparison to all crashes, documented that both multi- and single-vehicle truck crashes tend to occur on weekdays while "all" crashes (including passenger cars, light trucks, and vans) are at their highest levels on weekends.

b. The results of this test confirmed that truck crashes occur primarily on business days (that is, Monday through Friday).

3.2.3 Distribution of Crashes by Time of Year

Test Purpose/Goal

Researchers performed this test to determine patterns of crashes over the course of a year and the influence that weather might play in predicting crashes.

The goal of the test was to determine if seasonal weather conditions influenced crash patterns.

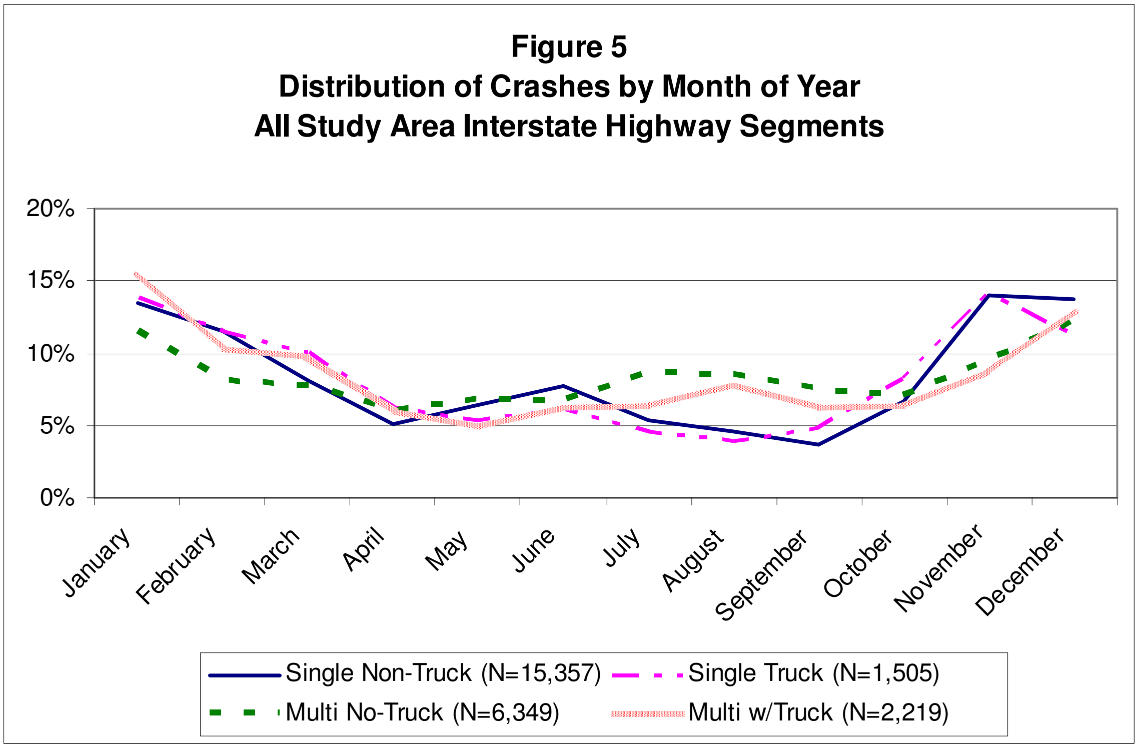
Test Findings

a. Winter months in Minnesota (November through March) experience the highest number of crashes during the course of a year.

Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.

b. The entire statewide sample of rural interstate crashes was used in this analysis.



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. The results of this test determined that single-vehicle truck crashes peak during the winter months in Minnesota, November through March.

3.2.4 Crash Contributing Factors

Test Purpose/Goal

Researchers performed this test to determine what influencing factors may contribute to freeway crashes and, specifically, whether influencing factors for truck crashes differed from all crashes and whether influencing factors for single-vehicle truck crashes differed from all other crashes.

The goal of the test was to determine if single-vehicle truck crashes had a higher incidence than other crashes that were attributed to influencing factors, such as drivers being asleep.

Test Findings

a. For the great majority of all types of crashes (more than 80 percent of crashes), drivers are described in the accident record database as being in "normal" condition when reporting on contributing crash factors.

b. Contributing factors identified include being ill, having been drinking alcohol, being under the influence of drugs, unknown factors and being asleep.

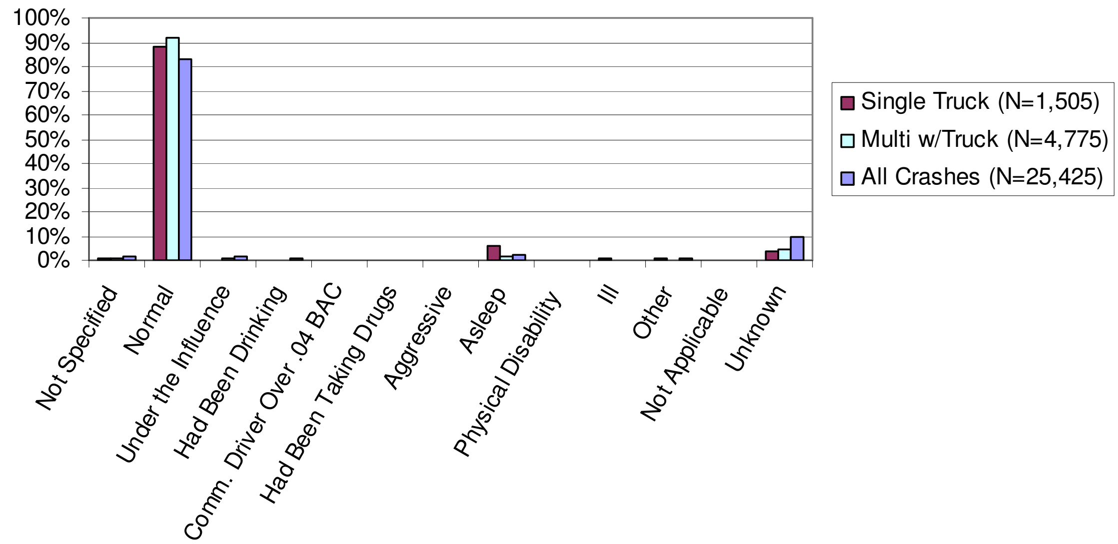
c. For single-vehicle truck crashes, being asleep was listed as a contributing factor at a rate almost three times greater than and almost five times more often than for multi-vehicle truck crashes (as shown in Figure 7 Specific Contributing Factors).

Data/Methodology

a. Data representing all times of day was used in this analysis and was aggregated on a statewide level.

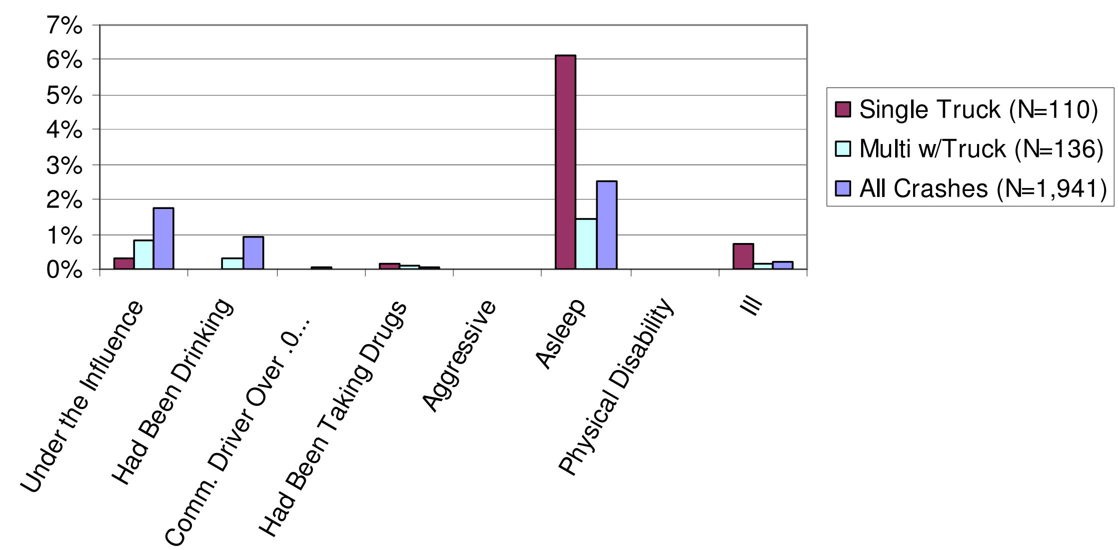
b. The entire statewide sample of rural interstate crashes was used in this analysis. The crash data was separated into single-vehicle truck crashes and multi-vehicle truck crashes. All crashes (including passenger cars, pickups, SUVs, vans, and motorcycles in addition to truck crashes) were also considered.

Figure 6
Distribution of Crashes by Physical Condition of Driver
All Study Area Interstate Highway Segments



Note: Some data records were not included due to incomplete attribute data.

Figure 7
Distribution of Crashes by Specific Physical Condition of Driver
All Study Area Interstate Highway Segments



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. The results of this test concluded that drivers falling asleep occurred four times more often than other known contributing factors combined for single-vehicle truck crashes.

3.2.5 Truck Crashes in Relationship to Interchange Location

Test Purpose/Goal

Researchers performed this test to determine if the distance from an interchange had an effect on where truck crashes occurred.

The goal of the test was to determine if crash rates increased corresponding to the distance from an interchange.

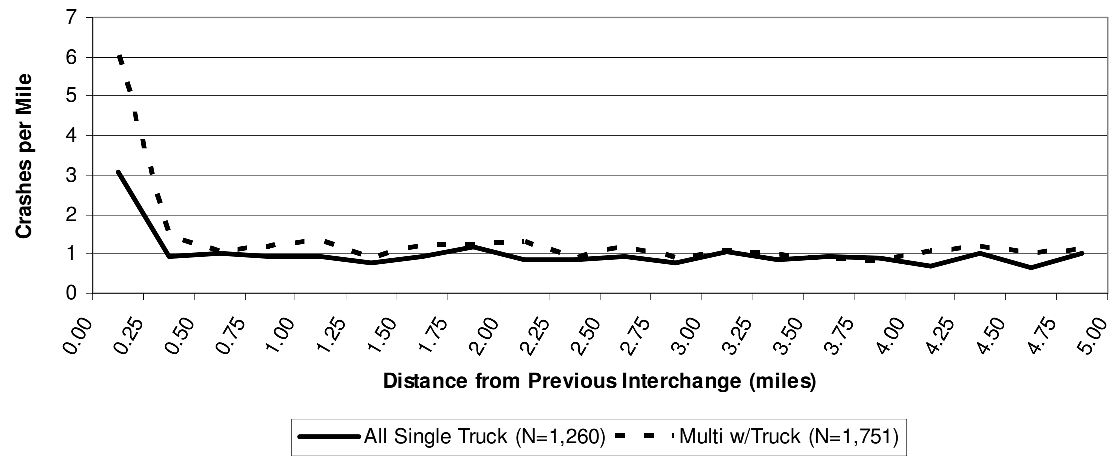
Test Findings

a. Truck crashes occur disproportionately within the first one-quarter-mile downstream of interchange on-ramps.
b. Truck crashes at distances greater than one-quarter-mile downstream from interchange on-ramps are relatively constant.

Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.
b. The entire statewide sample of rural interstate crashes was used in this analysis. The crash data was separated into single-vehicle and multi-vehicle truck crashes.
c. The crashes analyzed in this test were normalized by total miles of interstate downstream from interchanges.

Figure 8
Distribution of Truck Crash Rates by Distance from Previous Interchange
All Study Area Interstate Highway Segments



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. Vehicle-to-vehicle interactions at merge points appear to cause crashes that would not otherwise occur on the mainline segments of rural interstate freeways.

b. There may be a number of contributing factors that play a role in the number of crashes occurring within the first one-quarter-mile downstream of interchange on-ramps. These factors may include geometric design issues, sight distance, weaving and merging patterns associated with vehicle access.

3.2.6 Truck Crashes in Relationship to Freeway Traffic Volumes

Test Purpose/Goal

Researchers performed this test to determine whether single-vehicle truck crashes had the same or a different relationship to levels of heavy commercial average daily traffic (HCADT) than did multi-vehicle truck crashes.

The goal of the test was to identify the relationship between HCADT and single-vehicle crashes in order to establish a predictive measure for knowing where the greatest risk of crashes was to be found.

Test Findings

a. Typically, crashes of all vehicle types increase by the amount of vehicle miles traveled – in other words, the greater exposure there is to risk, the greater the risk to the traveler.

b. This expected pattern – relating crashes to volumes – was seen when looking at multi-vehicle truck crashes. However, a different pattern emerged when looking at single-vehicle truck crashes.

c. Single-vehicle truck crashes experience the highest crash rates at HCADT levels under 3,000 vpd and experience lower crash rates at higher HCADT levels where multi-vehicle truck crash rates are greatest.

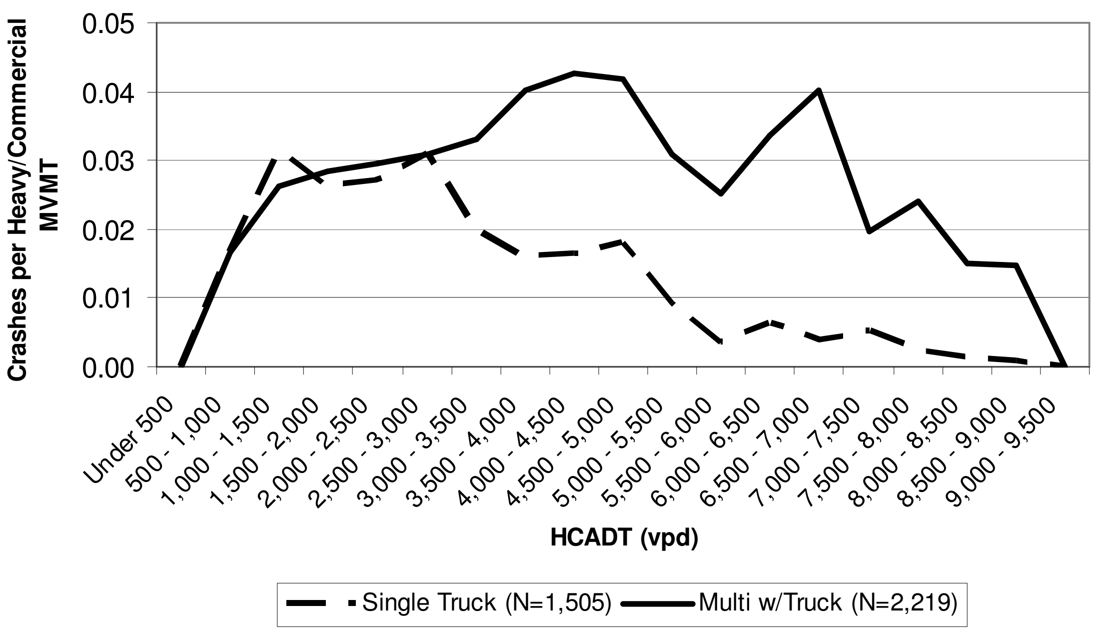
Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.

b. The entire statewide sample of rural interstate crashes was used in this analysis. The crash data was separated into single-vehicle truck crashes and multi-vehicle truck crashes.

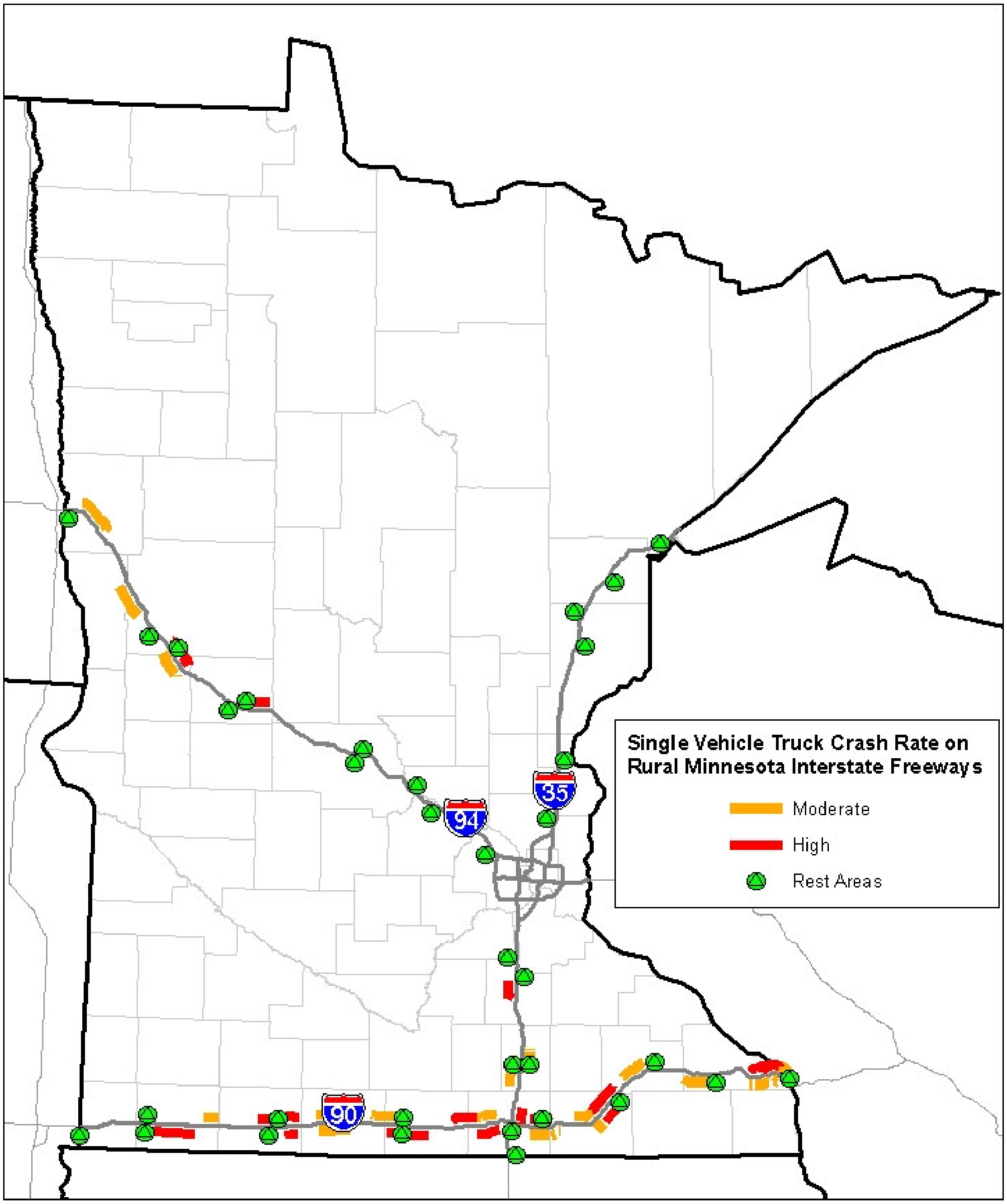
c. The crashes analyzed in this test were normalized by million vehicle miles of travel (MVMT) of heavy/commercial vehicles occurring in the entire study area during the study period.

Figure 9
Distribution of Truck Crash Rates by HCADT
All Study Area Interstate Highway Segments



Note: Some data records were not included due to incomplete attribute data.

Figure 10: Single-Vehicle Truck Crash Rate on Study Area Interstate Highways (N = 1,505)



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. Based on the results of this test, it was concluded that single-vehicle truck crashes are more likely to occur on lower-volume freeway segments than multi-vehicle truck crashes.

b. A greater proportion of all single-vehicle truck crashes are expected to occur at low HCADT levels compared to multi-vehicle truck crashes.

c. Single-vehicle truck crashes experience the highest crash rates at HCADT levels under 3,000 vpd and experience lower crash rates at higher HCADT levels where multi-vehicle truck crash rates are greatest. Figure 10 illustrates locations on the rural interstate freeway system experiencing a higher-than-expected incidence of single-vehicle truck crashes relative to truck volumes. This can indicate that highlighted segments have a similar number of crashes as other segments but lower truck volumes or similar truck volumes but more crashes than other segments.

d. I-90 has a disproportionate amount of high truck crash rate segments compared to other interstates in the study area. This is due to both consistently low HCADT values and large numbers of single-vehicle truck crashes.

3.2.7 Safety Rest Area Spacing and Single-Vehicle Truck Crashes

Test Purpose/Goal

Researchers performed this test to determine whether there was a relationship between safety rest area spacing and single-vehicle truck crashes (i.e., the greater the spacing, the higher the number of crashes).

The goal of the test was to identify whether a similar relationship between safety rest area spacing and crashes existed in Minnesota as was documented in the Taylor and Sung study.

Test Findings

a. There is a relationship between the distance from safety rest area and single-vehicle truck crashes at all times of day (specifically, the greater the distance between safety rest areas, the higher the number of downstream crashes). In other words, there is a high level of predictive ability when looking at incidents of single-vehicle truck crashes relative to the distance from a safety rest area.

b. This relationship between the distance from a safety rest area and crashes did not hold true when looking solely at nighttime crashes.

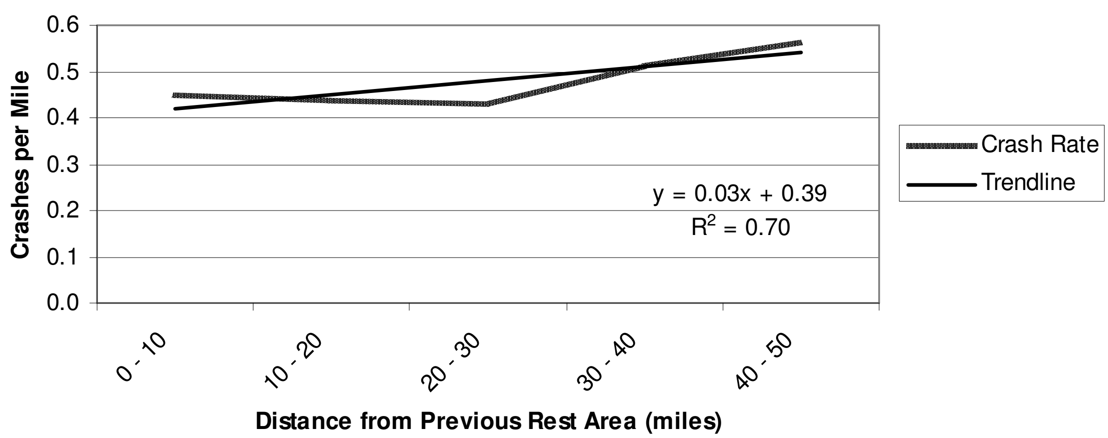
Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.

b. This sample included a subset of all single-vehicle truck crashes in order to eliminate contributing factors and to develop a data sample for drivers falling asleep at the wheel. Although driver fatigue may also contribute to the crashes that are coded to other factors, it was unclear how to measure the degree to which this occurs. In this test, researchers decided to exclude the following types of crashes from the dataset:

   - Crashes involving a collision with a deer or other animal.
   - Crashes occurring under road surface conditions coded as "snow," "slush," and "ice/packed snow."
   - Crashes where the driver's physical condition was coded as being "under the influence," "had been drinking," "commercial driver over .04 BAC)," "had been taking drugs" and "ill."

Figure 11
Single Truck Crash Rate (without other contributing factors) by Distance from Previous Rest Area (All Times of Day)
All Study Area Interstate Highway Segments, N=586



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. Similar to the Taylor and Sung study, researchers concluded that there was a positive relationship between safety rest area spacing and single-vehicle truck crashes during all times of day. This relationship is illustrated in the trendline depicted in Figure 11, showing an r-square value of 0.70.

3.2.7 Safety Rest Area CMV Parking Demand and Nighttime Single-Vehicle Truck Crashes

Test Purpose/Goal

Since 1995 Mn/DOT has been measuring nighttime CMV parking use in existing rest areas. It is generally understood that a surplus in parking in one highway segment or rest area cannot fulfill the demand at another. It is not well understood what the impact of a shortage of available nighttime CMV parking may have on highway safety. Researchers performed this test to determine whether there was a relationship between the percent of nighttime CMV parking capacity filled at a rest area and single-vehicle truck crashes (i.e., the greater the percent filled, the higher the number of crashes).

Test Findings

a. Test results indicated that safety rest area CMV parking demand does have good predictive capabilities in relationship to nighttime single-vehicle truck crash rates. In other words, the higher the safety rest area CMV parking demand, the greater chance that a nighttime single-vehicle truck crash would result downstream from the safety rest area.

Data/Methodology

a. All data used in this analysis was aggregated on a statewide level.

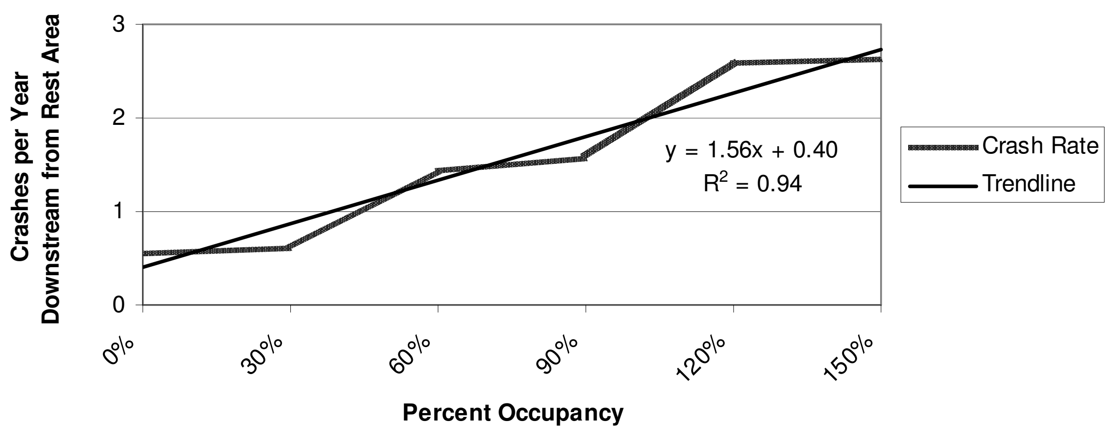
b. This test was a departure from tests conducted in the previous Taylor and Sung study, specifically because Mn/DOT has available data on the number of trucks parking at rest areas during nighttime hours.

c. Nighttime truck parking counts at safety rest areas showed percent of parking capacity levels of more than 200 percent in some instances. In this instance, given the existence of outliers such as those in the data sample (see discussion in Section 2.3.3.4), the decision was made to "cap" percent of parking capacity levels at 150 percent (i.e., safety rest areas in which the data indicated a greater than 150 percent of parking capacity level, which accounted for approximately three percent of the entire data sample). Data samples that exceeded 150 percent were not included in the analysis.

d. Crashes with other contributing factors were included in this test, not excluded as described in 3.2.7.b.

e. CMV parking data was only available during nighttime hours. Therefore, only crashes occurring during nighttime hours were included in the test. This resulted in a reduced sample size.

Figure 12
Nighttime Single Truck Crash Rate by Rest Area Percent of Parking Capacity Filled
All Study Area Interstate Highway Segments, 7 Days/Week, N=162



Note: Some data records were not included due to incomplete attribute data.

Conclusion

a. The strong relationship shown in the trendline illustrated in Figure 12 indicates that there is a good capability in using safety rest area CMV parking demand levels as a predictor of nighttime single-vehicle crash rates. An example of how this could be used is to look at a rest area that is, on average, 90 percent occupied throughout the year. Based on this analysis, it is estimated that the roadway segment downstream from this safety rest area will see between 1.5 and two nighttime single-vehicle truck crashes over the year.

b. The difference between varying percent of parking capacity levels can also be evaluated. For example, if a safety rest area had an percent of parking capacity level of 40 percent throughout the year, about one nighttime single-vehicle truck crash would be expected on the downstream segment. If the percent of parking capacity filled were 100 percent, however, two crashes would be expected, thus doubling the nighttime single-vehicle truck crash rate.

4.0 Study Conclusions

4.1 Safety Rest Area Spacing and Single-Vehicle Truck Crashes

There is a relationship between safety rest area spacing and single-vehicle truck crashes during all times of the day (i.e., the greater the spacing, the higher the number of crashes). However, this relationship did not hold true when looking only at nighttime single-vehicle truck crashes. Since nighttime hours were previously identified as having disproportionate numbers of single-vehicle truck crashes (relative to HCADT) and as these crashes were attributed to drivers being asleep at greater rates than other crashes, this finding is somewhat contradictory. Additional research is needed to determine the nature of this discrepancy and what conclusions to draw as a result.

4.2 Safety Rest Area CMV Parking Demand and Single-Vehicle Truck Crashes

There is a relationship between high safety rest area CMV parking demand and high rates of nighttime single-vehicle truck crashes. This relationship is seen whether viewing five-day (Monday through Friday) or seven-days-of-the-week data. Statistical tests conducted indicated that safety rest area CMV parking demand had good predictive capabilities for nighttime single-vehicle truck crashes. Based on this analysis, it is estimated that a roadway segment downstream from a safety rest area at 90 percent truck parking capacity during nighttime hours would see between 1.5 and two nighttime single-vehicle truck crashes over the year. This can be contrasted with the expectancy of one nighttime single-vehicle truck crash that would be anticipated downstream of a safety rest area well under nighttime parking capacity or 40 percent occupied on average. Additional research is needed to establish the relative benefits and costs of increasing truck parking capacity at safety rest areas to determine the appropriate policy response to this finding.

4.3 Similarity to Michigan Study (Taylor and Sung, 2000)

One of the main objectives of this study was to replicate, using Minnesota data, the methodology used in the Taylor and Sung study. In that study, it was discovered that there was a relationship between safety rest area spacing and the incidence of nighttime single-vehicle truck crashes. Researchers did not replicate this finding in the Minnesota study (see Sections 3.2.7 and 4.1). However, the Minnesota study did find a relationship between safety rest area CMV parking demand and the incidence of nighttime single-vehicle truck crashes. One possible explanation for the discrepancy between the Taylor and Sung and Minnesota studies may be that there are relatively few safety rest areas spaced more than 50 miles apart in Minnesota (e.g., only six out of the 34 in this sample were spaced more than 50 miles apart, with only one of the 34 spaced more than 60 miles apart). A policy inference that may be drawn from this finding is that the spacing of safety rest areas in Minnesota is adequate; however, nighttime commercial-vehicle parking capacity may be a safety issue that needs to be addressed.

4.4 Data Limitations

The data used in this research may contain some limiting factors. One element not included in the crash data was trip length or route prior to the crash occurrence. Therefore, it is not known if a driver of a vehicle involved in a crash on the rural interstate system had passed the previous safety rest area because it was full or he/she did not want to stop. The researchers assumed here that most commercial truck trips on the study routes are long-distance trips where drivers do not stop or turn on frequently. Additional research in this area may yield more conclusive results.

Appendices

A. Advisory Team

B. Crash Record Data Fields

C. Analysis Tests

D. Results of Analysis Tests (CD-ROM)

Appendix A: Advisory Team

The Highway Safety Rest Area Study was overseen by a multi-disciplinary group of Mn/DOT planners and engineers and a consulting firm providing technical expertise. Advisory team members included the following individuals:

Carol Reamer, Mn/DOT, Office of Technical Support (Project Manager)

Lori Laflin, Mn/DOT, Office of Investment Management, Market Research Unit (Technical Manager)

Marcus Evans, Mn/DOT, Office of Traffic, Safety and Operations

Loren Hill, Mn/DOT, Office of Traffic, Safety and Operations

Joe Kern, SRF Consulting Group, Inc.

Chris McMahon, Mn/DOT, Office of Investment Management, Market Research Unit

Paul Morris, SRF Consulting Group, Inc.

Kathryn O'Brien, SRF Consulting Group, Inc.

John Tompkins, Mn/DOT, Office of Freight and commercial Vehicle Operations

Rob Williams, Mn/DOT, Office of Technical Support

Appendix B: Crash Record Data Fields

Field Code	Description
ROUTE NUMBER	ROUTE SYSTEM AND ROUTE NUMBER
REF POINT	REFERENCE POINT
ELEM	INTERCHANGE ELEMENT CODE
RELY	RELIABILITY OF LOCATION INFORMATION
INVES	INVESTIGATING OFFICER
DIST	DISTRICT (MN/DOT CONSTRUCTION DISTRICT)
CNTY	COUNTY NUMBER
TWNP OR CITY	CITY OR TOWNSHIP NUMBER
DATE	DATE ACCIDENT OCCURRED
TIME	TIME OF DAY ACCIDENT OCCURRED
SEV	SEVERITY OF ACCIDENT
#VEH	NUMBER OF VEHICLES INVOLVED
JUNC	RELATIONSHIP TO JUNCTION
LIMIT	SPEED LIMIT
TYPE	TYPE OF ACCIDENT
DIAG	DIAGRAM OF ACCIDENT
LOC 1	LOCATION OF FIRST HARMFUL EVENT
TCD	TRAFFIC CONTROL DEVICES
LIGHT	LIGHT CONDITIONS
WTHR1 & WTHR 2	WEATHER CONDITIONS (2 POSSIBLE)
SURF	ROAD SURFACE CONDITIONS
CHAR	ROAD CHARACTER
DESGN	ROAD DESIGN
VTYPE	VEHICLE TYPE
DIRTN	DIRECTION VEHICLE WAS TRAVELING
ACTIN	ACTION BY VEHICLE/PEDESTRIAN/BICYCLE
FCTR 1 & FCTR 2	CONTRIBUTING FACTORS (2 POSSIBLE)
PCOND	PHYSICAL CONDITION
AGE	DRIVER AGE
SEX	DRIVER SEX
ACCIDENT NUMBER	ACCIDENT NUMBER

Appendix C: Analysis Tests

The following can be used as a key to navigating through study tests as included in this appendix on the enclosed CD-ROM. For example, if interested in a general analysis test looking at crashes by time of day, the user would refer to Section B tests and then look for Section B.1 tests.

B. General analysis tests included:

1. Crashes were graphed on the test segment by time of day (X-coordinate, time-of-day/Y-coordinate, percentage of crashes). *Purpose: Look for patterns of crash occurrence by time of day.*
2. Crashes were graphed by day of week (X-coordinate, day of week/Y-coordinate, percentage of crashes). Results of this test will be normalized to account for changes in HCADT over these periods. *Purpose: Look for patterns of crash occurrence by day of week.*
3. Crashes were graphed by month of the year (X-coordinate, month/Y-coordinate, percentage of crashes). Results of this test will be normalized to account for changes in HCADT over these periods. *Purpose: Look for patterns of crash occurrence by month.*
4. Crashes were graphed relative to physical condition of the driver (X-coordinate, physical condition of driver/Y-coordinate, percentage of crashes). *Purpose: Look for patterns of human factors relative to percentage of crashes.*
5. Crashes were graphed relative to road surface condition (X-coordinate, road surface/Y-coordinate, percentage of crashes). *Purpose: Look for patterns of road surface conditions relative to percentage of crashes.*
6. Crashes were graphed relative to roadway characteristics (X-coordinate, roadway characteristics/Y-coordinate, percentage of crashes). *Purpose: Look for patterns of roadway characteristics relative to percentage crashes.*
7. Crashes were graphed relative to AADT (X-coordinate, AADT/Y-coordinate, percentage of crashes). *Purpose: Identify the influence of AADT relative to percentage of crashes.*
8. Crashes were graphed relative to HCADT (X-coordinate, HCADT/Y-coordinate, percentage of crashes). *Purpose: Identify the influence of HCADT relative to percentage crashes.*

C. Detailed analysis tests included:

1. Crashes occurring on the test segment were graphed relative to their milepost occurrence (X-coordinate, milepost). Safety rest area location will also be indicated relative to its milepost. *Purpose: Look for any broad pattern of accidents that may be generally occurring on the test segment, especially relative to safety rest area location.*

2. Crashes were graphed as a function of distance from previous safety rest area (X-coordinate, distance from safety rest area (at 2-mile increments)/Y-coordinate, percentage of crashes). Net highway miles will be reported as well as a function to normalize net highway miles. *Purpose: Identify whether a relationship exists between safety rest area spacing and crashes on interstate highways.*

3. Crashes were graphed as a function of distance from previous interchange (X-coordinate, distance from interchange (at 2-mile increments)/Y-coordinate, percentage of crashes). Net highway miles will be reported as well as a function to normalize net highway miles. *Purpose: Identify whether a relationship exists between interchange spacing and crashes on interstate highways.*

4. Test c.i. (above) was analyzed with respect to time of day in addition to milepost occurrence of crashes. (X-coordinate, milepost/Y-coordinate, time of day). *Purpose: Look for patterns of crashes related to milepost location by various times of day.*

5. Test c.ii (above) was analyzed with respect to time of day in addition to distance from previous safety rest area. (X-coordinate, distance from previous rest area/Y-coordinate, time of day). *Purpose: Look for patterns of crashes related to distance from previous safety rest area location by various times of day.*

6. Text c.iii. (above) was analyzed with respect to time of day in addition to distance from previous interchange. (X-coordinate, distance from previous safety rest area/Y-coordinate, time of day). *Purpose: Look for patterns of crashes related to distance from previous interchange location by various times of day.*

7. Reproduction of Taylor and Sung Figure B-12 depicting distribution of HCADT and percentage of truck crashes by time of day. Calculate the (correlation coefficient). (X-coordinate, hour of the day/Y-coordinate, percentage). *Purpose: To gauge the significance of the relationship of the variables.*

D. Statistical analysis included:

   i. Distance from previous safety rest area
   ii. Distance from previous interchange
   iii. Safety rest area CMV parking demand
   iv. AADT
   v. Time of Day*
   vi. Day of Week*
   vii. Month*
   viii. Road Surface Conditions (related to pavement conditions affected by weather) *
   ix. Roadway Characteristics*

   * "dummy" variable in which a "yes/no" condition is reflected.

   x. An additional step in this analysis considered safety rest area CMV parking demand as a "dummy" variable for over-filled parking capacity at safety rest areas, in which various capacity thresholds are set, varying from 60 percent to 140 percent occupied, in increments of ten percent.

E. Special Analysis

   i. Nighttime truck percent of parking capacity filled analysis

      1. Nighttime truck percent of parking capacity filled at safety rest areas relative to distance from previous safety rest area (X-coordinate, safety rest area/primary Y-coordinate, distance from previous rest area/secondary Y-coordinate, safety rest area CMV parking demand). Purpose: Identify trends relative to safety rest area spacing and average rest area CMV parking demand.

      2. Nighttime truck percent of parking capacity filled at rest areas relative to average segment HCADT at rest area locations (X-coordinate, safety rest area/primary Y-coordinate, segment HCADT/secondary Y-coordinate, safety rest area CMV parking demand.) Purpose: Identify trends relative to HCADT and safety rest area CMV parking demand.

      3. Nighttime truck percent of parking capacity filled relative to day of week (X-coordinate, day of week/primary Y-coordinate, safety rest area CMV parking demand.) Purpose: Identify trends related to day of week and safety rest area CMV parking demand.

4. Nighttime truck percent of parking capacity filled relative to month of year (X-coordinate, month of year/primary Y-coordinate, safety rest area CMV parking demand.)

5. Analysis of crash data relating to safety rest area CMV parking demand on the day that the crash occurred (X-axis, percent percent of parking capacity filled of safety rest areas/Y-axis, percentage of crashes occurring at a particular percent of parking capacity level) Purpose: Identify the relationship between high levels of safety rest area CMV parking demand and increased crash occurrences.

ii. Statistical Analysis

6. Similar to the analysis in d., safety rest area CMV parking demand was examined as part of the special analysis

F. Additional Analysis

i. Group “Distribution of Nighttime Crashes by Rest area CMV parking demand” in D.e.i.3 by different scales (i.e. 20%, 25%, 30%, etc) to eliminate zero values and increase statistical significance.

1. Analyze I-90 and I-94 corridors for nighttime single-vehicle truck crashes and nighttime “asleep” single-vehicle truck crashes

2. Show all 7 days of week and cap percent of parking capacity filled at differing levels

3. Show Monday-Friday subset and cap percent of parking capacity filled at differing levels

4. Highlight results of any tests with R-square value greater than 0.5

ii. Eliminate Contributing Factors from nighttime single truck crashes to develop data sample for drivers falling asleep at the wheel.

1. From “TYPE” category codes 8 (collision with deer) and 9 (collision with other animal) were eliminated. From “SURF”, or road surface conditions, category codes 3 (snow), 4 (slush), and 5 (ice/packed snow) were eliminated. From “PHYS”, or driver’s physical condition, category codes 2 (under the influence), 3 (had been drinking), 4 (commercial driver over .04 BAC), 5 (had been taking drugs), and 9 (ill) were eliminated.

2. Run analysis for daytime, nighttime and 24 hour total

3. Use this data set to graph distance from previous rest area, includes grouping distances by 5 and 10-mile scales.

4. Highlight results of any tests with R-square value greater than 0.5