MONTANA REST AREA USAGE:

DATA ACQUISITION AND USAGE ESTIMATION

by

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ABSTRACT

Rest areas perform a critical role in the highway network. They provide passenger vehicle occupants and heavy vehicle operators with an opportunity to use a restroom, walk around, stop for a meal, sleep for a period of time, or even pause to use a cellular phone. For decision-making related to rest area usage, many states, including Montana, consult the American Association of State Highway and Transportation Officials (AASHTO) "*A Guide for the Development of Rest Areas on Major Arterials and Freeways*" (AASHTO, 2001). This reference provides guidance related to rest area design, including water and sewer system capacity, as well as parking lot size and layout.

The Montana Department of Transportation (MDT) is currently reviewing the applicability of the figures provided in this document for various rest area design aspects, because they are based on national averages that may not represent usage patterns in a rural state like Montana.

The objectives of this research were threefold: to 1) obtain rest area usage data that could support various aspects of rest area planning, design, and operations in the future; 2) process, manipulate, and compile data in a format that can be used by MDT in general activities and by the researchers for analysis in subsequent project activities, and 3) develop rest area usage guidelines, including recommended procedures that could be used in predicting rest area usage in the state of Montana. In completing objective 1), four separate types of data were collected during the course of this project: traffic data, dwell time data, water usage data, and patron/door count data. However, this project is most concerned with the traffic data and the associated percent usage.

Analysis of descriptive statistics indicated that the mean usage at rest areas in the high volume interstate category was approximately 10 percent of mainline traffic. The average percent mainline traffic entering for the low volume interstate category was approximately 8.7 percent. This value was 10.96 percent for the high volume arterial category and 13.39 percent for low volume arterials.

INTRODUCTION

General Overview

Rest areas perform a critical role in the highway network. They provide passenger vehicle occupants and heavy vehicle operators with an opportunity to use a restroom, walk around, stop for a meal, sleep for a period of time, or even pause to use a cellular phone. Many of these activities aid in reducing driver fatigue, with the potential for consequently reducing fatigue-related crashes. These various activities also have a direct impact on a number of aspects of rest area design, from parking stall demand to facility sizing, water needs and wastewater generation and handling.

Many states, including Montana, consult the American Association of State Highway and Transportation Officials (AASHTO) "*A Guide for the Development of Rest Areas on Major Arterials and Freeways*" (AASHTO, 2001) for information regarding rest area usage. This reference provides guidance related to rest area design, including water and sewer system capacity, as well as parking lot size and layout. The Montana Department of Transportation (MDT) is currently reviewing the applicability of the figures provided in this document for various rest area design aspects, because they are based on national averages that may not represent usage patterns in a rural state like Montana.

MDT's rationale is that rest areas located along lower volume rural roadways receive higher percentages of mainline volumes of vehicles/patrons than those estimated by AASHTO, owing to fewer opportunities to stop elsewhere. If the traffic volume estimates for a rest area are inaccurate, then the prediction of sizing and usage based on these figures may be inadequate as well. Consequently, MDT is concerned about under-designing a facility, thus requiring costly renovations and expansion at a future date. On the other hand, MDT is also concerned about over-designing a facility in order to make the best use of scarce financial resources. Finally, MDT would also like to predict and track the expected life of rest area facilities based on asset management processes, which require extensive amounts of usage data.

As a result of these concerns and needs, research was necessary to refine the figures employed in the estimation of Montana rest area use. In particular, it was necessary to obtain Montana-specific figures related to rest area usage including water flow, effluent flow, pedestrian traffic, vehicle traffic counts and classifications, and vehicle dwell times for commercial vehicles and passenger vehicles. This information will provide MDT with up-to-date figures that may be employed in usage estimation for rest area design and rehabilitation activities. Such estimation was essential in the process of planning and designing rest area facilities. The use of state-specific figures will facilitate fiscally sound decision-making, through the avoidance of facility over or under design.

Finally, all of this information would be of limited usefulness without guidance related to its implementation. Therefore, it is also necessary to develop guidance to aid in employing (and updating) rest area usage rates in the future.

Background

At present, there are 34[1] state-maintained (i.e., MDT maintained) rest areas on Montana highways, of which 14 are dual rest areas — that is, facilities are provided in the two directions of travel. This includes 18 located along Interstate routes (four single and 14 dual), as well as 16 located along the non-Interstate National Highway System and primary state routes, leaving a total of 48 individual state-maintained rest area sites. A map of these sites is provided in Figure 1 (page 45).

The condition of these rest area sites varies significantly. Some rest areas are recently constructed (Anaconda) while others are older and in need of repair (e.g., Raynolds Pass). One of the important issues faced by many existing sites is the condition of the well and septic systems. Systems at many sites are overwhelmed because current use has exceeded the design. In addition, there has been an evolution toward more stringent requirements for the design or rehabilitation of such systems by the Montana Department of Environmental Quality. These issues are directly related to the number of vehicles and patrons visiting a rest area each day. Finally, accurate information related to usage is essential to support MDT asset management processes, which require quality data for extended periods of time. The availability of such data will allow MDT to predict and track the expected life of rest area facilities.

Several sites are slated for closure, replacement, or rehabilitation, and new facilities have been programmed for construction at a future date. Crucial to sites that

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[1] For the purposes of this thesis, the figure of 34 rest areas will be cited. The reader should note that some of these sites are dual, i.e., a separate building is present on both sides of the highway. Therefore there are a total of 48 rest area buildings at 34 rest area locations.

will remain open or be constructed is an understanding of the traffic (vehicle and patron) that they receive and the resulting impact on facilities (water use, wastewater generation, parking needs, etc.). Accordingly, obtaining such usage data from all state-maintained sites and developing guidance related to its use for future planning and design purposes is essential to ensuring the continued provision of rest areas that meet the public's need while achieving an optimum use of MDT's financial resources.

Research Objectives

The objectives of this research were threefold: to 1) obtain rest area usage data that could support various aspects of rest area planning, design, and operations in the future; 2) process, manipulate, and compile data in a format that can be used by MDT in general activities and by the researchers for analysis in subsequent project activities, and 3) develop rest area usage guidelines, including recommended procedures that could be used in predicting rest area usage in the state of Montana. In completing objective 1), four separate types of data were collected during the course of this project: traffic data, dwell time data, water usage data, and patron/door count data. Recommended procedures to estimate traffic/parking demand using factors were developed from observed vehicle and patron count data. Estimated wastewater generation factors were developed based on recorded data for entering patron traffic.

Thesis Overview

This research thesis is organized in five chapters. Chapter 1 presents an introduction to the research, including the objectives and purpose of this research project as well as a brief summary of the current state of Montana's rest area program. Chapter 2 presents a literature and practice review which summarizes previous research on rest areas conducted to date as well as an overview of the current national state-of-the-practice in regards to rest area usage. Further, Chapter 2 presents the results of a survey conducted with rest area planners from a sample of state Departments of Transportation (DOTs). Chapter 3 contains details on the data collection phase of this project for each type of data including procedures, methodologies, challenges, and general results. Chapter 4 presents the results of data analysis efforts including summary statistics and statistical analyses of the data collected and analyzed by data type. Chapter 5 offers recommendations on Montana rest area usage estimation, including vehicular and patron traffic as well as vehicular dwell time and wastewater usage estimation.

LITERATURE AND PRACTICE REVIEW

This chapter reviews rest area literature related to usage and estimation, traffic demand, and other relevant topics. Additionally, it presents a summary of the practices employed in Montana, as well as other states (identified in conjunction with MDT staff) regarding rest area planning and design. This portion of the work was accomplished through a personal survey of practitioners.

Literature Review

The following sections summarize literature related to various aspects of rest areas, with a specific focus on design and planning issues. This previous research includes work related to vehicular and patron usage estimation, as well as wastewater treatment (including discussion of typical systems employed and their effectiveness). In addition to an examination of design aspects, additional rest area-related research is covered. This includes work estimating accident reduction rates due to the presence of rest areas, as well as analysis of the possibility of allowing commercial activities at rest areas. These additional topics are presented to educate the reader more fully on additional aspects of rest areas that are being considered in different states.

Rest Area Usage

Many states including Montana consult the AASHTO publication "*A Guide for the Development of Rest Areas on Major Arterials and Freeways*" (AASHTO, 2001) for rest area design guidance. The section of this document that is of particular interest to this research is the estimated percentages of mainline traffic stopping at rest areas. According to the guide, 12 to 15 percent of traffic passing welcome centers stop, 8 to 13 percent of vehicles along recreational routes stop at rest areas, while 5.5 to 9 percent along broader use routes stop at rest areas. Recommended spacing for rest areas is 60 miles or one hour of driving time. The figures used in this document are based on approximate national usage rates for rest areas on arterial and freeway facilities.

AASHTO also provides equations for determining the required number of trash receptacles, parking spaces, restroom stalls, as well as many other site amenities within this guidance document. The guide cites the Minnesota, Virginia, and Washington State DOT's as sources for these equations. One equation of interest in this research is the number of car parking spaces N_c, which is given as:

$$N_c = \frac{ADT * P * DH * D_c * PF * VHS}{60}$$ [2]

Where:

- ADT = Average Daily Traffic
- P = proportion of mainline traffic stopping, multiplied by the ratio of DSL/BSL
  - DSL = design section length, the length of a chosen study section
  - BSL=base section length, the base length proposed by the AASHTO guide (60 miles or 100 km)
- DH = design hourly factor (DHV/ADT)
  - DHV = Design Hour Volume
- D_c = proportion of cars using facility, assumed 0.75

[2] Note: The equation is the same for truck parking except replace D_c with D_t, the proportion of trucks using the highway facility.

- PF = peak factor, ratio of average day usage during the 5 peak summer months compared with average over the entire year, assumed 1.8
- VHS= average dwell time, 15 minutes for cars and 20 minutes for trucks

The AASHTO guide provides tables of various values for the parameters included in this equation. This includes the ratio of Design Hour Volume (DHV) to Average Daily Traffic (ADT) presented in. Ranges of assumed values for the composition of the mainline traffic stream are presented in Table 2. Values for the percent of mainline traffic stopping are presented in Table 3. Finally, values for dwell times based on vehicle type are presented in Table 4.

Table 1: Design Hourly Volume Default Values

Vehicle Type	ADT≤12,500	ADT>12,500
Car	0.15	0.15
Truck	0.15	0.10

Table 2: Mainline Traffic Composition Default Values

Vehicle Type	Percent of total mainline traffic
Car	75 to 89
Cars with trailer and RV	4 to 9
Commercial trucks	7 to

Table 3: Percent Mainline Traffic Stopping

Vehicle Type	Location	Percent Stopping
Car	Near commercial area	9%
Car	Typical rural route	12%
Car	Info and Welcome centers	9 to 15%
Cars with trailer and RV	N/A	9 to 15%
Commercial Trucks	N/A	9 to 15%

Table 4: Expected Dwell Times and Factors

Parking Spaces	**Assumed dwell time**	**Factor**
Car	15 minutes	0.45
Cars w/ trailer	15 minutes	0.45
Trucks	20 minutes	0.60

The car and truck parking equation is of interest for several reasons. First, it incorporates information related to the proportion of mainline traffic entering a facility (and the proportion of that stream which are passenger vehicles). Each of these aspects was measured, as described in later chapters of this thesis, to facilitate analysis activities. In the case of the equation above, the proportion of passenger vehicles takes on an assumed value, whose source is not cited. The use of such an assumed value is likely to be of concern to many transportation agencies, as it may not accurately reflect local traffic conditions. Additionally, the source of the values employed for passenger and heavy vehicle dwell times are also not indicated. Based in part on the inclusion of such an assumption, dwell times at a sampling of sites are examined and discussed in a later chapter of this report.

The guide notes that the size and spacing of rest areas are inversely proportional. The closer the rest areas are spaced, the smaller the facility may be. AASHTO recommends that smaller, closely-spaced rest areas should be used for scenic routes, while larger, widely-spaced rest areas should be used on interstates, freeways and high-use commuter facilities.

AASHTO recommends that new rest areas be designed for a future Average Annual Daily Traffic (AADT) of 20 years from the expected completion of construction. The manual also suggests that an agency should conduct annual user surveys to determine the satisfaction of the rest area users. These were indicated as being helpful in determining what improvements should be implemented at existing sites, as well as included in future designs.

The National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board published Report # 324 (King, 1989) which examined a number of different aspects of rest areas. These included entering traffic trends, user profiles, dwell time observations, and current practices (number, spacing, facilities offered) employed by states. Much of the information presented by this report was compiled through on-site personal surveys of rest area users at 13 rest areas in 5 states, as well as telephone surveys.

The field data collected on-site at the 13 rest areas was used to estimate models for predicting the percentage (P) of mainline traffic that would use a rest area based on the distance between rest areas. Observations indicated that entering traffic ranged between 5.5 and 17.7 percent of mainline traffic, with an average entry of 10.3 percent. Linear regression analysis was employed to produce an equation estimating traffic entering a rest area from the mainline that was dependent only on the design section length (DSL). The equations developed were as follows:

- $P = 0.023 + 0.0027(DSL)$ when $DSL \leq 30$ miles
- $P = 0.062 + 0.0019(DSL)$ when $DSL > 30$ miles

Traffic data readily available from 43 rest areas in six states indicated that this equation typically underestimated the percentage of mainline traffic stopping at the rest area. Consequently, an additional equation of the form $P = 0.02 + 0.0029*DSL$ was developed based on this supplemental data. A non-linear equation was also developed from this supplemental data, which was of the form $P = 0.007*DSL^{0.81}$.

The research notes that models that fit the data better could have been developed using other variables such as traffic volume and composition, but a lack of data rendered these coefficients not statistically significant. The lack of data stemmed from collection activities occurring during different time periods; while the rest areas studied were generally not spaced very far apart (only two were spaced further than 50 miles).

User surveys found that the primary reason for stopping was either to rest or to use the restroom. Drivers making trips longer than 100 miles were more likely to use a rest area during a trip. A large decrease in use during the winter months was also found by the surveys. The report found a large variability in the percent of out-of-state rest area users. The surveys also produced demographic data of rest area users. Vehicles were occupied by an average of 2.2 people. About one-third was single-occupant vehicles (SOV). The average age of users was 42. Respondents indicated that they traveled an average of two hours or 130 miles between stops.

Similar to AASHTO's rest area guide, NCHRP #324 provided default values to use for mainline traffic existing interstates to use a rest area based on data collected during the course of the research. This information was intended to be applied when historical data was unavailable to an agency. This information is presented in Table 5.

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Table 5: Proportions of Mainline Traffic Entering Rest Areas

Distance between rest areas (D)	**Proportion (P)**
D ≤ 20 miles	□.06
20 miles < D ≤ 50 miles	0.003 * distance
> 50 miles	0.15

For staffed welcome centers, the calculated value of the percentage entering the rest area is increased by 0.05. These values need to be adjusted for non-interstate facilities, primarily rural highways depending on whether they are recreational routes. The equations developed to accomplish this adjustment were as follows:

- P = 0.67 * P (for interstate facilities on recreational routes)
- P = 0.50 * P (for interstate facilities on non-recreational routes).

Where:

P = proportion of passing traffic

When no historical data or other basis of estimation is available, the report presents alternative values as rough estimates for the percent of mainline traffic entering the rest area. This guidance is based on percentages of entering traffic by vehicle type. These estimates were also provided and are presented in Table 6.

Table 6: Percent Entering Rest Area by Vehicle Type

Vehicle Type	**Percent Entering**
All traffic	12%
Passenger cars (PC)	10
Commercial trucks	15%
Recreational vehicle (RV)	20%

Dwell time data were also recorded during on-site rest area visits. Field observations indicated that the mean dwell time at rest areas was 11.4 minutes, with a standard deviation of 12.87 minutes, a minimum duration of 1 minute and a maximum duration of 3 hours and 31 minutes. When the field data were disaggregated by vehicle class, it was found that cars spent an average of 11 minutes in the rest area, commercial vehicles 12.1 minutes, and recreational vehicles (RVs) 19.5 minutes.

The World Bank Transport and Urban Development Department (Yokota, 2004) summarized work completed in Japan, Kenya, and China on traffic counts and vehicle occupancy at rest areas. Their analysis found the percent of mainline traffic stopping as ranging between 5 and 20 percent based on the site and country. For example, if the site had special features such as a weigh station, 20 percent of mainline traffic was observed to stop. Additionally, vehicle occupancies were recorded, with results indicating passenger vehicles had an average occupancy of 2 persons, mini-busses 10 persons, large busses 30 persons, and commercial vehicles 1 person.

Garder and Bonosetto (2002) quantified roadside rest area usage in New England. This work, while primarily focusing on surveying rest area patrons, did discuss percentages of traffic visiting rest areas in New Hampshire, Vermont, Massachusetts and Maine. Additionally, the authors developed models to estimate passenger vehicle parking requirements in the New England area. Different models were developed based on the mainline AADT, the type of rest area (i.e. typical rest area, welcome center, etc.), and the distance to the nearest adjacent rest area. The models of parking requirements were as follows:

- 0.002 * AADT (for rest areas within 30 miles of another rest area)
- 0.003 * AADT (for rest areas further than 30 miles of another rest area)
- 0.006 * AADT (for isolated Welcome/Tourist Information Centers)

The New England report also presented results from a study conducted by the New Hampshire DOT from 1995-1998 at four rest areas. The results presented in this report provided the average percentage of mainline traffic using the rest areas. Depending on the site, the percentage of mainline traffic entering a rest area ranged between 3.2 percent and 9.1 percent (Garder and Bosonetto, 2002).

A Colorado DOT report by the Rest Area Task Force Committee (1997) looked at the condition of the state's rest areas (CDOT, 1997). The team looked at the current conditions as well as how to determine when renovations or reconstruction were necessary. A ranking system was developed based on the qualities of the rest areas that were most important to users, as well as which rest areas were most in need of improvement. The criteria employed were as follows:

- Spacing interval – spacing was between 35 and 60 miles to previous and next rest area
- Proximity of competing service – rest areas were located between gas stations or restaurants
- Transportation system servicing –the functional class of the highway served by the rest area
- Accessibility/proximity – was the rest area clearly visible from the highway and well marked by signage

- Visual appeal – the aesthetic appeal of the rest area
- Combined use – was the rest area combined with a welcome center, park, truck weigh station, etc.
- Parking capacity – adequate parking is provided and within reasonable walking distance from the facility
- Building and utility service system – the building's size, layout, and utilities meet the needs of the users; the building and utilities were easily maintained and/or repaired
- Truck accommodations –reasonable parking available for truck drivers who stay overnight
- Additional services – picnic tables, tourist information, pet walk areas, vending machines, etc. are provided.

The results of the weighting procedure indicated the most important criteria were: building and utilities service system, visual appeal, and parking capacity. Parking was based solely on a set AADT category related to the 2015 projections, with results presented in Table 7.

Table 7: Colorado Parking Design Table

AADT Category	2015 AADT	Auto Spaces	Truck/RV Spaces
1	0 - 7,000	20	10
2	7,000 - 20,000	40	15
3	20,000+	50	25

In addition to discussions of rest area entering volumes and parking requirements, two studies specifically examined heavy vehicle parking at rest areas. A Connecticut

DOT study on their rest areas in 2001 estimated that the state's demand for truck parking was approximately 1,600 spaces (Goods Movement Planning, 2001). At the time of the study, Connecticut rest areas only provided 345 heavy vehicle spaces statewide, indicating a need for the inclusion of additional spaces at rest areas or greater reliance on parking at private truck stops. A study by Wang and Garber (2003) of truck parking in the state of Virginia found that statewide, about 80% of the available truck parking was provided by private truck stops. Two linear regression models were developed to estimate the accumulation of trucks parking at a given rest stop by interstate. While these models are not presented here as they focus on an aspect of rest area use that differs from that being studied by the present research, they were found to be fairly accurate in predicting accumulation of trucks parking at interstate rest areas.

The most recent work with respect to traffic counts was performed in 2002-2003 for the Louisiana DOT (Griffin and Yan, 2003). Traffic count data were collected at four sites (three combination rest area/welcome centers and one stand-alone rest area) in different locations throughout the state. Data were collected using side firing radar installations mounted on light poles near the entrance or exit ramps of each rest area in a manner which captured both rest area traffic, as well as mainline traffic.

Only basic analysis of the traffic count data were performed, with no attempts made to develop models that explained rest area usage or predicted mainline entering traffic volumes. Rather, only the percentage of vehicles entering each rest area from the mainline traffic stream was determined. The percentage of vehicles stopping at a rest area varied dramatically from 2 percent to 20 percent, depending on the site. The researchers indicated that the site with 2 percent of vehicles stopping may have been the result of the majority of traffic on that route being local/commuter in nature. Aside from this general traffic analysis, the rest of the work performed by this project focused on water usage and wastewater generation, which are discussed in later sections of this chapter.

Adams and Reierson (1981) discussed the planning, location and design of rest areas based on work completed in Minnesota. Their discussion included the presentation of equations used at that time to determine the number of parking stalls required during the peak hour. To determine parking needs, a multi-step process was employed:

1. Compute Design Hour factor (DH)

   DH = (DHV/ADT)

   Where:

   - DHV = Design Hour Volume (projected for a 20-year design period)
   - ADT = Average Daily Traffic (projected for a 20-year design period)

2. Adjusted vehicle stopping percentage (P)

   P = Percent mainline stopping * (DSL/BSL)

   Where:

   - Percent mainline stopping = the percentage of traffic expected to stop at the rest area (based on surveys of rest area users)
   - DSL = Design section length, route segments that correspond to logical breaks on a route

- BSL = Base section lengths, the desired spacing interval of rest areas (ex. 50 miles)

3. Calculate required parking spaces for passenger vehicles and commercial vehicles

   N_c = (ADT * P * DH * D_c * PF)/VHS

   Where:

   - N_c = number of passenger vehicle stalls required
   - ADT = Average Daily Traffic (projected for a 20-year design period)
   - P = Adjusted vehicle stopping percentage
   - DH = Design Hour factor
   - D_c = distribution of parking stalls to cars (as percentage), based on observations and surveys from other sites
   - PF = Peak factor, a factor that accounts for the highest use month
   - VHS = vehicles per hour per parking stall, based on observations

This work further recommended that a spacing interval of 50 miles (80 km) be employed, based on the fact that this represented approximately one hour's travel time at the prevailing national speed limit of the time (55 mph).

In addition to the work already discussed, two additional studies focused solely on dwell time at rest areas. A study by the Nebraska Department of Roads reported the mean time spent in rest areas by vehicle class (NDOR, 1987). Passenger vehicles showed a mean dwell time of 15.5 minutes, commercial vehicles 30.4 minutes, and RVs 23.6 minutes. A study in the state of Michigan presented seasonal differences in dwell times between passenger and commercial vehicles for six rest areas (Twardzik and Haskell, 1985). Passenger vehicles had a mean dwell time of 6.7 minutes in the winter and 10.1 minutes in the summer, while commercial vehicles displayed dwell times of 12.6 minutes in the winter and 14.6 minutes in the summer.

The Rest Area Use Study Procedure Guide (ODOT, 1960) was developed primarily by the Oregon State Highway Department. It provided specific instructions on how to assess rest area usage and condition. It also gave examples of forms to be used in data collection as well as guidelines on how to perform this collection and what information was needed. Personal observations and user surveys were recommended for field collection. Road tube traffic counters were recommended for installation at the entrance of a rest area as well as the mainline highway upstream of the rest area to obtain data on the percentage of mainline vehicles entering the rest area.

Byrne (1991) studied the usage of three rest areas in Vermont in 1989. Hourly entering traffic volume data was collected from mid-May to the end of October. At the same time, permanent counting stations near each rest area provided directional hourly volumes of traffic on the mainline, allowing percentages of entering traffic and peaking characteristics to be determined. Results determined that the percent of vehicles entering the study sites from the mainline ranged from 7.7 percent to 14.4 percent depending on the day and month being examined. At the site producing the average of 14.4 percent entering traffic, the daily and monthly variations were shown to be rather small; the greatest difference found was approximately four percent on Thursdays.

Linear regression models were developed in an attempt to produce prediction equations for several sets of possible variables. Equations were initially of the form $y = a + bx$, with the value of *a* for each model tested to see if it was significantly different from zero. In most cases, this was found to not be true, therefore the model was changed to have the following form: $y = bx$. Models were developed using five combinations of rest area and mainline peak hour and daily traffic volumes, with separate models developed for each individual rest area.

The coefficients and R square values of the models developed varied widely due to the different variables employed in their development. The models developed using the rest area peak hour volume as the dependent variable and mainline volume at the same rest area during the peak hour as the independent variable produced R square values ranging from between 0.52 to 0.76 (a value of 1.0 indicates a direct relationship between the independent and dependent variables). The models developed using the rest area daily volume as the dependent variable and the daily mainline volume as the independent variable, produced R squares value ranging between 0.33 and 0.91. This would seem to indicate that for at least one site, there was a significant relationship between the daily traffic volume entering the rest area and the daily mainline traffic volume passing the site. However, the author does not discuss why this site may have produced a better model result than others.

Perfater (1989) studied rest area usage at eleven combination rest area and welcome centers in Virginia. Specifically traffic counts and dwell times were recorded at the sites, and rest area usage surveys were distributed to patrons. Results showed an average of 12 percent of mainline passenger vehicles entered the rest area versus 23 percent of the mainline truck traffic. Heavy vehicle percentages varied greatly, ranging between 10 percent and 40.6 percent depending on the site. Vehicle occupancy rates were observed during the course of data collection activities, and are presented in Table 8.

Table 8: Vehicle Occupancy Rates

Vehicle Classification	**Rest Area Occupancy Rate**	**Welcome Center Occupancy Rate**
Passenger car	1.80	1.90
Light truck	1.25	1.30
RV	2.05	2.10
Motorcycle	1.20	1.30

Dwell time results indicated that the average dwell time for a passenger vehicle was 9.1 minutes, while large vehicles remained at rest areas an average of 15 minutes. The author further noted that the average dwell time for passenger vehicles during the summer was approximately 10 minutes. It is assumed that the data used to determine this summer average was also employed in determining the overall average for passenger vehicles, as no further specifics are provided.

Melton et al. (1989) conducted a study to update the state of Washington’s current practice on rest area design. Site visits were conducted at eight rest areas, while traffic counts were obtained for all rest areas in order to provide guidance on estimating the required number of parking stalls. Manual data collection spanned six hours at each site, collecting the following information in 15 minute intervals:

1. Number of vehicles entering
2. Type of vehicle entering (car, truck, vehicle w/trailer, and recreational vehicle)

3. Number of passengers in each vehicle
4. Number of males/females entering restrooms
5. Random recording of vehicle dwell time

Based on the data collected, it was found that the proportion of traffic entering rest areas on average days varied between 6 and 21.5 percent. During peak periods, this figure ranged between 7.5 and 44 percent.

This work also developed guidelines for parking demand based on designs to meet the needs of 85% of the peak hour parking demand. The step-by-step process developed by this work first determined future average daily traffic (ADT) from traffic counter data and then multiplied the ADT by percentages of vehicles observed entering rest areas. Percentages ranged from 5 to 12 percent depending on the location of the rest area. This produced the number of vehicles per day entering the rest area. This average was then multiplied by 2 to 4 percent to obtain peak parking demand. Again, the value employed depended on the location and type of rest area. A rest area near a town was viewed to serve more commuters, which give a higher parking turnover rate; therefore the percentage employed was 2 percent. A rest area on a recreational route served a different traffic mix which gave a lower parking turnover rate; therefore the percentage employed was closer to 4%.

Water and Wastewater

In addition to traffic-related guidance, the AASHTO rest area guide presents information with respect to water usage at rest area sites (AASHTO, 2001). The guide recommends that restroom facilities be split with 60% for women and 40% for men, based on the assumption that women will utilize the restroom for a longer duration. Water usage is estimated using the following equation, with an assumed 13.25 liters (3.5 gallons) of water used per person:

PHD = ADT*B*PF*UV*13.25 liters (or 3.5 gallons)+employee flow

Where:

- PHD = Peak Hourly Demand
- ADT = Average Daily Traffic
- B = ratio of design hourly volume to ADT (assumed as 0.15)
- PF = Peak Factor, the ratio of the average day used during the five summer months of peak usage compared with the average day usage over the entire year (assumed as 1.8)
- P = total percent of traffic stopping at the rest area
- UV = restroom users per vehicle (assumed as 1.3)
- Employee flow = water required by maintenance employee (i.e. cleaning)

Based on the results of this equation, an agency would have an estimate of the water needs for a rest area. Additionally, while wastewater considerations are not discussed by the AASHTO guide, one may employ the assumption that the water being used at the rest area (i.e. clean water going in) is approximately equal to the wastewater being generated at the site (dirty water going out). This assumption may then be employed in other design aspects, such as the design of septic fields (when city sewer connections are not available).

Gregory et al (1977) discussed the wastewater treatment practices at rest areas. The research team made field visits to rest areas in 21 states. They found that at that time, most rest area wastewater treatment was done in a similar manner to that of the average domestic wastewater treatment. The researchers also found that the criteria used in designing these facilities varied greatly from state to state. The hydraulic loading rates ranged from 10.2 to 22.7 L (2.7 to 6.0 gal) per person per day and an organic bio-chemical oxygen demand (BOD_5) loading ranged from 2.7 to 9.1 g (0.006 to 0.02 lb) per person per day. It was also found that because of the lack of adequate design criteria, most systems have been overdesigned. The researchers cite that references in their research estimated these ranges as 16.1 to 21.8 L per vehicle per day and 125 to 200 mg/L for BOD_5.

Griffin and Yan (2003) examined water usage and wastewater generation in their work for the Louisiana DOT. Water data was collected using water meters connected to a data logging device. Waste generation data was also collected using ultrasonic sensors. The data established that water usage could be an effective measure of estimating wastewater production, as most of the water/waste ratios found in this study were close to 1.0 (mean = 1.4). The amount of wastewater produced per vehicle varied from 3.0 gallons/vehicle to 7.3 gallons/vehicle, depending on the site.

Erickson et al. (1981) briefly discussed wastewater treatment at rest areas in the state of Michigan. The two types of systems studied were septic tank systems and lagoon systems. These were then broken down into further subtypes: septic tanks with tile fields, septic tanks with leaching pits, septic tanks with sand-filters with overland flow evapotranspiration, lagoons with seepage beds or lagoons with overland flow evapotranspiration. The stated advantage of a lagoon system versus a septic tank was that lagoons provided storage during the winter season when land-treatment systems would not operate as well.

Each of these systems was evaluated by sampling the wastewater before and after treatment, the soil at various depths, and the water table around the area of the wastewater treatment facility. Results of the tests are presented in Table 9 and Table 10, indicating the percent reduction of each pollutant tested for in each treatment system.

Table 9: Septic Tank Efficiency

		OF-ET (%)*	
Pollutant	**Sand Filter (%)**	**200 ft**	**800 ft**
Biological Oxygen Demand	87	62	91
Total Phosphorous	70	75	89
Total Nitrogen	28	55	98
Suspended Solids	83	N/A	62
Fecal Coliforms	99	N/A	99

* OF-ET = Overflow evapotranspiration

Table 10: Lagoon Efficiency

Pollutant	**Concentration (ppm)**	**Reduction (%)**
Biological Oxygen Demand	2.5	96
Total Organic Carbon	32.7	48
Inorganic Phosphate Phosphorus	0.09	97
Total Kjeldahl Nitrogen	1.9	97
Ammonium Nitrogen	0.12	99
Nitrate Nitrogen	0.45	0
Total Nitrogen	2.35	94
Water	N/A	87

Fowler, et al. (1989) discussed various plumbing and wastewater topics as part of their study on the required designs for rest areas in Texas. Of specific interest is a discussion of the unique waste disposal needs of recreational vehicles. While the research does not provide formal guidance, it does provide instructive information about the nature of the sewage held in recreational vehicle tanks. This type of sewage often contains cleaning solutions, and disposing it in rest area treatment systems (such as septic fields) overwhelms that system. As a consequence, in many locales, it may be necessary to include a recreational vehicle treatment system separate from that of the system employed for the rest area facility.

As part of the study that Melton et al. (1989) conducted in the state of Washington, guidance was provided to help estimate water/wastewater use based on the estimated future traffic demand (Melton et al., 1989). The following equation was developed to calculate peak water demand:

Gallons Used during Peak Hour = $ADT_{seasonal}$ * $\%_{entering}$ * Occupancy * $\%_{use}$ * Gallons

Where:

- $ADT_{seasonal}$ = The seasonal ADT for the site
- $\%_{entering}$ = Percentage of vehicles entering rest area (estimated to be 5-12% based on previous data)
- Occupancy = average vehicle occupancy (estimated to be 2 based on previous data)
- $\%_{use}$ = Percentage of people using restroom (estimated to be 70% based on previous data)

- Gallons = Gallons of water used per person (estimated to be 3.5 based on previous data)

Montana Rest Area Studies

The Montana Rest Area Plan completed in December, 1999 (amended in May, 2004), provided recommendations for various aspects of rest area planning to employ in Montana as related to location and development, design, operations, maintenance, and other considerations (Blomquist et al, 1999 and Blomquist and Carson, 2002). Much of this guidance was adapted from AASHTO's rest area guide, with Montana-specific recommendations developed for the various aspects covered.

As part of the update of the rest area plan, a survey of Montana rest area users was conducted in 2002. The survey contained four sections: rest area usage questions, travel-related questions, demographic questions, and opinion questions. Rest area usage questions asked survey participants about their reasons for stopping and their familiarity with Montana rest areas. Opinion questions asked about the condition of the rest area, if there were enough amenities available, and whether the location was appropriate (spacing). Travel-related questions included length of trip, type of vehicle driven (passenger vehicle vs. heavy vehicle), how many people were traveling, and the purpose of the trip. The demographic questions asked about age, gender, marital status, residence, previous education, and income. Surveys were conducted at 16 of the state's rest areas over the course of two days at each site. In total, 2000 surveys were distributed, with 1053 responses given, equating to a 53% response rate.

Notable results of the surveys relevant to the present research include: 61% of the users were out-of-state visitors, and 69% were traveling for recreation. Approximately 64% of respondents were making a trip longer than 1,000 miles. The average occupancy per vehicle was 2.73 people.

The most common qualitative rating of overall satisfaction with the rest area facility was “very good”. Most of the complaints were related to maintenance at the site. Many respondents indicated more rest areas were needed in the state.

Additional Research

While traffic-related and water/wastewater aspects of rest area literature were the primary focus of this review, the research team identified additional information of interest during the course of this work. The following sections provide an overview of past work related to various aspects of rest areas which may be of interest to the reader.

NCHRP Report #324 examined the estimation of the reduction of accidents due to the presence of rest areas (King, 1989). A traffic accident rate (TAR) was used to measure the impact of rest areas on accident reduction. The work estimated that 10 percent of all highway accidents involved a fatigued driver. These figures did not account for fatal crashes, nor was the basis for this estimation provided.

Based on parametric equations developed to estimate reduction in TAR (not provided here for brevity), an approximated proportion of fatigued drivers and reduction in proportion of fatigued drivers due to the presence of a rest area was developed. Results indicated that reductions of up to 40 percent in accident rates were possible when rest areas were available. Of course, this reduction is premised on rest areas being available in the correct locations to address such accidents, which is not entirely possible.

A study by Taylor and Sung (2000) modeled the effect rest areas have on fatigue-related crashes on rural freeways in the state of Michigan using truck crash data collected from 1994-1997. Due to the lack of information on fatigue-related crashes, single vehicle truck crashes were used as a surrogate for fatigue-related crashes. A relationship between single vehicle crashes involving heavy trucks and rest area spacing was developed, with heavy truck crashes also related to the time of day.

Results indicated a much higher probability of single vehicle truck crashes between midnight and 8 a.m., indicating that fatigue may be a strong factor in such crashes. Further linkages to the fatigue factor came from the finding that the probability of a single vehicle truck crash occurring on a rural freeway segment increased when the distance from the previous rest area exceeded 30 miles.

Some states have examined the possibility of transferring ownership and operation of rest areas from state agencies to private enterprises. The impetus for this transition stems from a lack of federal funding toward rest area programs, limiting their expansion. This limitation would conceivably be addressed by allowing businesses such as gas stations and fast-food restaurants to occupy rest area locations, with those enterprises paying a fee to the state for conducting business on state-owned right-of-way.

Gattis and Tooley (1997) surveyed businesses that were currently or would potentially participate in a commercialized rest area program (primarily gas station and fast-food restaurants). At that time, it was illegal to have private business at a rest area except in the case of turnpikes or toll roads nationwide. This was predicated on 23 U.S.C. s.111 and 23 CFR s.752.5. This is still active governance, except where states have been grandfathered-in, have been accepted into the Interstate Oasis Program, and/or have successfully petitioned for an exception. The authors pointed to the success privately-owned rest areas on turnpikes and toll roads have had, including generating revenue for the state. Surveys indicated that typical practice was that at least one business at a rest area was open 24 hours a day, with food and fuel providers being the most common businesses present at commercialized sites. Minimum traffic volumes based on the proximity of competition, traffic volume composition (local versus long-distance) and prices all factor in to the potential success of a commercialized rest area. The authors concluded that careful attention to contract details was necessary when implementing a commercial rest area strategy.

Practice Survey of Selected States

As previously discussed, MDT and most other states use the AASHTO *Guide for Development of Rest Areas on Major Arterials and Freeways* to design and reconstruct rest areas. However, MDT rest area planners were interested in learning the exact processes and procedures employed by their counterparts in other states, which could potentially differ in some respects from the AASHTO guidance. Consequently, a survey was conducted with seven states regarding current rest area planning and design practices including: Montana (to record a baseline practice), Utah, Idaho, Washington, Wyoming, South Dakota, and Texas. Surveys were conducted by both telephone, as well as email questionnaire based on the preference and availability of the respondent. Additionally, rest area planning documents were reviewed, when available, for additional information of interest. Survey questions focused on aspects such as rest area facility sizing (building and parking) and spacing, preferred wastewater treatment systems, typical amenities provided, approaches to condition rating indices and reviewing cycles, and current funding sources, including partnerships.

Montana Practice

Currently the Montana Department of Transportation (MDT) is engaged in an asset management planning approach to managing rest area projects, including new construction, reconstruction and rehabilitation. The importance of such an approach is to conserve limited financial resources while sustaining and improving an aging infrastructure asset. The asset management approach provides MDT with a process to advance projects, in order of priority, matched to a dedicated funding source for efficient delivery and improved service to the travelling public.

For rest areas, the asset management process began with a statewide facility condition inventory in 2008 to determine a baseline condition for each rest area. This baseline condition list aided in the generation of a prioritized list of rest area work, absent of geographic boundaries within the state. The inventory was followed by partnership meetings to process the information and reach a project prioritization consensus. These meetings involved representatives from MDT Construction Engineering, Consultant Design, Maintenance Facilities Bureau, District Administration, District Maintenance, Planning, Motor Carrier Services, the Director's Office, and the Federal Highway

Administration's Montana office. The meetings aided in resolution of the list of prioritized projects and work types, resource allocation, project management, and established a process for advancing rest area projects in a timely, cost-effective manner according to proven asset management strategies. Upon full agreement on the list of projects, priorities and delivery methodology by the partnership committee, the MDT Director granted approval, followed by the Transportation Commission.

The on-going asset strategy is managed by committee, consisting of active representation from MDT Construction Engineering, Consultant Design, Facilities, Planning, and the FHWA's Montana office. Rest area priorities and projects are continually evaluated for efficiency, with the goal of timely project delivery and improved public service.

The AASHTO *Guide for Development of Rest Areas on Major Arterials and Freeways* (AASHTO, 2001) guide is currently the basis employed in Montana for estimation of facility size, number of restroom stalls, parking lot sizing, waste-water system capacity, water needs, and other factors. The *Montana Rest Area Plan* (Blomquist, et al., 1999) provides guidance on Montana rest area design. Current Montana design practice suggests rest areas should be spaced approximately one hour apart under desirable travel conditions. However, when selecting the location of a combined facility (i.e. port of entry or visitor information centers), the one hour spacing may be disregarded in order to place a facility at or near a state border or an intersection of multiple routes.

Minimum requirements to be considered for a potential rest area site include adequate area (footprint), a good water source, access to electricity, sewage and septic system (or ability to develop such a system), distance to any nearby community, and availability of emergency services. Additional features considered in the selection process include:

- Potential environmental impacts
- Tourist attraction proximity
- Corridor geometry (horizontal and vertical alignment for access to rest area)
- Ease of right-of-way acquisition
- Community acceptance

To select potential sites, overhead photos and topographic maps are reviewed to create a strip map of potential site locations. Thorough on-site evaluations are then performed following guidelines outlined in the site-selection form. This form is available in the Montana Rest Area Plan (not presented here for brevity).

The number of parking spaces required at a site is determined using the procedure outlined in the AASHTO guide. The process begins with the design year directional mainline AADT, which is converted to a design hourly volume (usually 10 to 15 percent of design ADT). With mainline traffic composition information, the number of vehicles per hour (vph) stopping at the rest area is determined depending on the location of the rest area and the amenities offered. Using average dwell times for each vehicle type estimated in the AASHTO guide (15 minutes for passenger vehicles and buses/RV's, 20 minutes for commercial trucks), the number of each type of vehicle entering the rest area is multiplied by a factor to determine the necessary number of parking stalls. The AASHTO guide also suggests the appropriate number of picnic tables and waste receptacles based on the number of vehicles entering the rest area. All components of the rest facility need to be compliant with the Americans with Disabilities Act.

Commercialized facilities at rest areas are currently prohibited by Montana state law. Federal law prohibits commercial activity at all rest areas located on interstate right-of-way with the exception of vending machines, for which proceeds go to Randolph Sheppard agencies (in Montana, these funds are provided to the State Association for the Blind).

MDT prefers to use municipal water and sewage treatment whenever possible. This system is most commonly used in rest areas adjoined to city parks. When this is not possible, a self-contained system is required. The majority of current on-site sewage treatment systems in Montana are septic tanks with a drain field.

All MDT facilities are required to meet state and local building codes and follow the permitting process for source and waste-water systems. Local partners, counties, and other state and federal agencies are involved throughout any rest area project, as applicable. Two primary areas of review involve the Montana Department of Environmental Quality (MDEQ): 1) source water requirements and analysis and 2) waste-water treatment and non-degradation requirements and analysis. Design for source water and waste-water systems must go through Montana DEQ review and approval prior to installation. On-going review of existing systems is conducted by the Montana DEQ, which includes sampling, testing, and reporting. Three additional aspects of wastewater handling should be stressed:

- MDT is subject to the clean water act and MDEQ wastewater system design and treatment regulations.
- Recreational vehicle waste generation will not be handled at Montana rest areas due to operations and maintenance demands.

Waste systems must be pertinent to Montana's climate and total daily flow waste generation (gallons per day).

Practices of Survey States

The following sections provide a summary of the practices employed in rest area design by Utah, Idaho, Washington, Wyoming, South Dakota, and Texas. Inquiries were made with each state regarding the approaches employed in sizing and spacing rest areas, design of wastewater systems, and whether condition indices were developed. A high-level summary of information related to each of these topics is provided by Table 11. Additional details of interest provided by each state are presented in the following sections. Some states provided more information than others regarding different aspects of their rest areas.

Table 11: State Practices for Rest Area Design

State	Sizing by AASHTO?	Spacing by AASHTO?	Wastewater Treatment System	Condition Indices Developed?
Idaho	Yes	Yes	Lagoon pond Leech field	No
South Dakota	Yes	Yes	Lagoon pond	Yes
Texas	No[1]	Yes	Lagoon pond Septic tank	Yes
Utah	Yes	Yes	Septic systems Lagoon ponds	Yes
Washington	Yes	Yes	STEP systems Septic system Non-discharging lagoon	Yes
Wyoming	Yes	Yes	Septic system Leech field	Yes

1 In sizing rest area facilities, TxDOT does not use the AASHTO guidelines as they have been deemed too conservative. Texas employs a standard of approximately 28 truck parking spaces and 18 passenger vehicle spaces per rest area. These are altered as needed.

Idaho: Information related to rest area practices in the state of Idaho was provided by Brent Jennings of the Idaho Department of Transportation (ITD). ITD's rest area program consists of three major categories of rest areas:

- Gateway – these are essentially port-of-entry sites at the entrances into the state.
- Deluxe – an intermediate level in which full services are provided
- Basic Plus – the lowest level for lesser traffic areas in which basic amenities are provided i.e. potable water, flush toilets, and picnic tables.

The amenities provided by ITD depend on the type of facility, but include the items found at most rest areas (parking, restrooms, etc.). Rest area funding primarily comes from the federal government via FHWA. In the State Transportation Improvement Plan (STIP), five million dollars a year is set aside specifically to the safety rest area program, cut recently from ten million dollars. In addition to these funding sources, one rest area in the state is considered an oasis, and receives separate federal funding under a special program. Several partnership opportunities are currently being pursued by the agency to further cover the expenditures associated with rest areas.

South Dakota: Information related to rest area practices in the state of South Dakota was provided by state highway engineer Mike Behm of the South Dakota Department of Transportation (SDDOT). SDDOT measures and tracks elements within the rest area facility utilizing building software to identify treatment, alteration, and modification triggers. Once triggered these elements are reviewed by staff for final recommendations on how they should be addressed.

Amenities provided at South Dakota rest areas include separate parking for passenger vehicles and large trucks, picnic shelters, kiosks, walking paths, pet walking areas, restrooms, drinking fountains, telephones, and tourism brochures (maps, tourist sites, etc.). Tourism staff is present during summer months to provide travel assistance.

Rest areas in South Dakota are typically built using federal funds, with a state match. Other state agencies may participate in the funding process if elements of the rest area benefit their mission. South Dakota currently does not have any public or private partnerships for any of its rest area facilities. However, in certain circumstances, other neighboring states may participate in funding if the facility benefits them, such as port of entry facilities.

Information related to rest area practices in the state of Texas was provided by Safety Rest Area Program Manager Andy Keith of the Texas Department of

Transportation (TxDOT). Rest area amenities in Texas include two sets of restrooms for each gender, with five to six fixtures in each. Buildings typically have lobby areas containing interpretive exhibits showing local geographic and historical information about the area around the rest area facility. All of Texas' rest areas provide free wireless internet.

All rest area maintenance is contracted out to private contractors. TxDOT uses condition ratings as incentives for the maintenance companies to maintain the rest area in a satisfactory manner. A maintenance contractor may receive bonuses of up to 15 percent if the condition is determined to be above a certain rating. Conversely, a maintenance contractor will be required to provide a refund to TxDOT if maintenance at a site is deemed unacceptable.

Funds for Texas' rest area program come from Transportation Enhancement (TE) funding. A certain percentage of that funding is allocated specifically to rest area maintenance and construction. Projects qualify for Federal TE funds if they fall under at least one of 12 categories of transportation enhancement projects outlined by the FHWA (FHWA, 2010).

Utah: Information related to rest area practices in the state of Utah was provided by Utah Department of Transportation (UDOT) Facility Maintenance Manager Bill Juszcak, as well as the Utah Statewide Rest Area Plan (UDOT, 2007). At present, there are six different types of facilities in Utah's rest area system. The different types and some basic features of each type are described below.

- View Area - This is a basic area provided to take advantage of scenic viewing opportunities. These only provide basic amenities, i.e. parking and restrooms.
- Rest Area - These facilities correspond to those defined by AASHTO in the rest area guide. Parking, restrooms, tables and benches, and basic traveler's information are often provided at these sites.
- Welcome Center - Similar to rest areas except more traveler information is provided.
- Public/Private Partnership Rest Stop - Essentially a privately-owned rest area. The site provides the free services typically provided by a rest area 24 hours a day, 365 days a year, with some form of commercial business such as a gas station or restaurant also present.
- Public/Public Facility - A rest area jointly owned by UDOT and some other public entity that provides services. This may include a rest area jointly owned by UDOT and the US Forest Service for example.
- Port of Entry - Port of entry facilities include checkpoints for commercial vehicles. All commercial vehicles must stop at these sites and report required information, as well as be inspected, if necessary.

The amenities provided by Utah at a rest area depend on the intended use of the site. In addition to the typical amenities (i.e. restrooms,), amenities that may be provided include vending machines, Wi-Fi internet access, and playgrounds. The condition of UDOT rest areas is rated, employing the following system:

- Age: number of years since original construction, reconstruction, or major upgrade of the facility.
- Conformance (Compliance) with current design standards: 0 = good; 0.5 = fair; 1 = poor.
- Primary Structure Condition and Appearance: Interior and exterior elements of the building. Subjective rating during inventory: 1=very good 2=good 3=fair 4=poor 5=very poor.
- Overall Site Condition and Appearance: Everything else besides the primary structure. Subjective rating during inventory: 1=very good 2=good 3=fair 4=poor 5=very poor.

Traditional federal funding comes from the Interstate Management (IM) program, the National Highway System (NHS), and the Surface Transportation Program. Other non-traditional programs that are recognized as potentially providing federal funds to aid rest area construction/rehabilitation include Transportation Enhancement funds (TE) and the FHWA Interstate Oasis Program. The Interstate Oasis Program involves certain sites that can be commercialized with private business in order to alleviate the financial burdens associated with rest areas.

<u>Washington:</u> Information related to rest area practices in the state of Washington was provided by Maurice Perigo of the WSDOT Safety Rest Area program, as well as Washington's Safety Rest Area Strategic Plan (WSDOT, 2008). The classification and amenities provided at a rest area depend on the type of rest area being designed for a site. Washington has developed four different classes of rest areas, designated as C-1 through

C-4, with C-4 being the most basic and C-1 including the greatest number of amenities. A list of the classes and amenities provided at safety rest areas is provided in Table 12.

Table 12: Washington Rest Area Classifications and Amenities

Class	**Designation**	**Site Features/Services**	**WSDOT Sites**
Class 1	C-1	• All Class 2 features • 24/7 Operation Travelers Information Center	16
Class 2	C-2	• All Class 3 features • Picnic Tables • Drinking Water • Vending Machines • Paved Parking Areas • Lighted Walkways • Commercial Truck Parking • RV Dump Stations (optional)	25
Class 3	C-3	• All Class 4 features • Vault toilets	5
Class 4	C-4	• ADA Accessible Passenger Car Parking • No restrooms	44

Current funding for rest areas comes from federal dollars similar to many other states. Several options for partnerships are also being looked into by WSDOT. These include the Oasis Program (see the previous section for Utah for a description of this program), the Green Highways Partnership (with the FHWA and the Environmental Protection Agency to make highway construction and maintenance more environmentally friendly), and a partnership with the Washington Department of Ecology (DOE, examining how to reduce emissions from idling commercial trucks).

Wastewater generated at Washington rest areas may be handled through a number of different systems, including Step systems, on-site septic systems, and on-site lagoons. Step systems collect the solids from a rest area facility into a septic tank, and then pump the treated effluent to a municipal system (i.e. sewer) for final treatment. On-site septic systems employ a septic tank followed by a drain-field system. This system has been found to work well for low use sites that see small wastewater flows. On-site non-discharging sewage lagoons are viewed by WSDOT to be the most efficient and eco-friendly option for wastewater treatment. A sewage lagoon collects, treats, and disposes of all wastewater from a facility with no energy input, as natural biological activity degrades organics, the sun's ultraviolet rays provide for disinfectant, and the wind and sun evaporate liquids. The drawbacks are large land surfaces are needed, and a dry, hot region is ideal.

Wyoming: Information related to rest area practices in the state of Wyoming was provided by Assistant Architectural Projects Coordinators Josh Anderson and Cheryl Packard of the Wyoming Department of Transportation (WYDOT). Amenities provided at Wyoming rest areas include restrooms, drinking fountains, state maps and brochures, and picnic areas. Some rest areas also have playground equipment, dog runs, designated walking paths, and RV dump stations.

Wyoming has a condition rating system in place for all DOT buildings; however a system does not exist specifically for rest area facilities. The system contains ratings for 36 different elements of a building, some of which would not relate to rest area facilities. Some ratings are weighted based on importance, one of which is an overall condition rating. A high ratings number indicates a greater necessity for improvement or replacement.

Wyoming's rest area facilities are funded by federal dollars as facilities are located on the National Highway System. One rest area is partially funded through a partnership with the town of Powell, with the community providing janitorial services for the facility.

WYDOT relies on an internal report from 1999 which contained recommendations to modify the approach to sizing wastewater treatment systems for rest areas. The equation developed to accomplish this slightly differs from that suggested by AASHTO to determine wastewater production, and is as follows:

$$Q_{ave} = TC \times U \times N \times q \times SF$$

Where:

- Q_{ave} = Average wastewater flow
- TC = Mainline traffic count, vehicles per day
- U = Usage rate or percent entering (range = .04-.27; average= .11)
- N = Average vehicle occupancy (range = 2.23-3.12; average = 2.72)
- q = Average wastewater flow generated per person (range = 1.84-3.60; average = 2.53)
- SF = Safety Factor (Engineer's judgment; suggested range = 1.05-1.25)

Chapter Summary

This chapter has presented the results of a literature review which examined past research and agency reports examining various aspects of rest area usage, estimation and design. It has also summarized the current practices employed in Montana and a sample of states regarding rest area design, evaluation, and funding aspects.

Various research has been conducted that has measured traffic count data, dwell time, water usage, and wastewater production at rest areas - occasionally in combination. However, all of these studies have employed a small sample size of sites. Many studies focused on user surveys, which are a valuable tool in helping state's determine what improvements could be made to increase the use of facilities, but do not effectively quantify statewide rest area usage. Similarly, work estimating traffic entering a rest area depends on many variables, many of which were not accounted for in the research conducted. Values of the percentage of vehicles leaving the mainline, dwell time of cars and trucks, and percentage of trucks in the mainline traffic stream all are variables affecting rest area usage, but in most cases, existing research examined such variables apart from one another (i.e. only one of these variables was examined, with the others neglected).

The most notable finding of the literature review, as it pertains to the research work conducted and described in this thesis, was that previous research indicated water usage data is a reasonably accurate estimate of wastewater production for a rest area/welcome center (Griffin, 2003). This is valuable as water usage data is easier to collect than wastewater production data. The obvious benefit of this finding to the research at hand is that it required only water usage data to be collected via water meters.

In examining state practices, Montana practice typically matched that of the other states surveyed. As one might expect, the amenities provided at rest areas were typically the same, with only some minor differences existing (ex. the provision of free Wi-Fi in some states). Similarly, the funding sources employed by other states were similar to those of Montana, with funds coming from Federal and state government sources; one exception was Utah, where Public/Private partnerships have been put into place in some instances. Condition rating systems exist in varying degrees from state to state. In some cases (Wyoming), these rating systems are basic, examining only aspects of the buildings themselves and are part of a larger, agency-wide approach. In other cases (Utah), a specific approach tailored to rest areas has been developed. Finally, information from Washington and Wyoming indicates that, while the specifics involved in estimating/sizing wastewater systems may differ, the approaches to handling wastewater at rest area sites are similar.

DATA COLLECTION

The data collected throughout the course of this project can be broken into four categories: traffic count data, vehicle dwell time data, door counter data, and water meter data. Traffic count data are an essential piece of information in rest area planning, because the number of vehicles entering a rest area directly relates to all aspects of its design. These data, along with vehicle dwell time (the duration a vehicle occupies a parking space) data, govern the estimation of parking demand at a rest area. Door counter data can assist in estimating the required number of restroom stalls. Also, door counter data in conjunction with water meter data can be used to estimate the wastewater produced to determine the capacity required for a wastewater treatment system at a site.

Overview of Study Sites

This project examined all rest areas maintained by MDT, with a few exceptions. Data for the Dearborn site was not collected because the rest area was taken out of service for reconstruction during the study. Further, Locate and Dupuyer were not considered in later analyses because water usage data would not be collected at them as they employed vaulted toilets; these sites were also low-volume and would require minimum design standards. A list of the rest areas investigated in this project, along with relevant information, is presented in Table 13. A map showing study site locations is presented in Figure 1.

Table 13: List of Study Sites

Site	Dual (Y=Yes)	Mainline	2008 Mainline AADT*
Anaconda		I-90	10875
Armington		US-89, US-87**	3940(US-89), 590 (US-87)
Bad Route		I-94	3336
Bearmouth	Y	I-90	8245
Bozeman		I-90	17494
Bridger		US-310	3713
Broadus		MT-59	905
Clearwater Junction		MT-200, MT-83	3257 (MT-200), 1688 (MT-83)
Columbus	Y	I-90	10259
Culbertson		US-2	1070
Custer	Y	I-90	3954
Dena Mora	Y	I-90	6209
Divide	Y	I-15	3854
Emigrant		US-89	1927
Flowing Wells		MT-200,MT-24	525 (MT-200), 164 (MT-24)
Gold Creek	Y	I-90	8631
Greycliff	Y	I-90	7090
Hardin	Y	I-90	6035
Hathaway	Y	I-90	4093
Hysham	Y	I-90	3830
Jefferson City	Y	I-15	6229
Lost Trail Pass		MT-43, US-93	841 (US-93), 297 (MT-43)
Mosby		MT-200	328
Quartz Flats	Y	I-90	6377
Raynolds Pass		US-287	1745
Roberts		US-212	2621
Sweetgrass		I-15	2424
Teton	Y	I-15	3879
Troy		US-2, MT-56	3097 (US-2), 1034 (P-56)
Vandalia		US-2	1299
Vista Point		US-212	375

*** Average annual daily traffic. Note, for interstate sites, the AADT presented is for both directions.**

** At sites located at T-intersections, AADT from the nearest station on each leg is provided

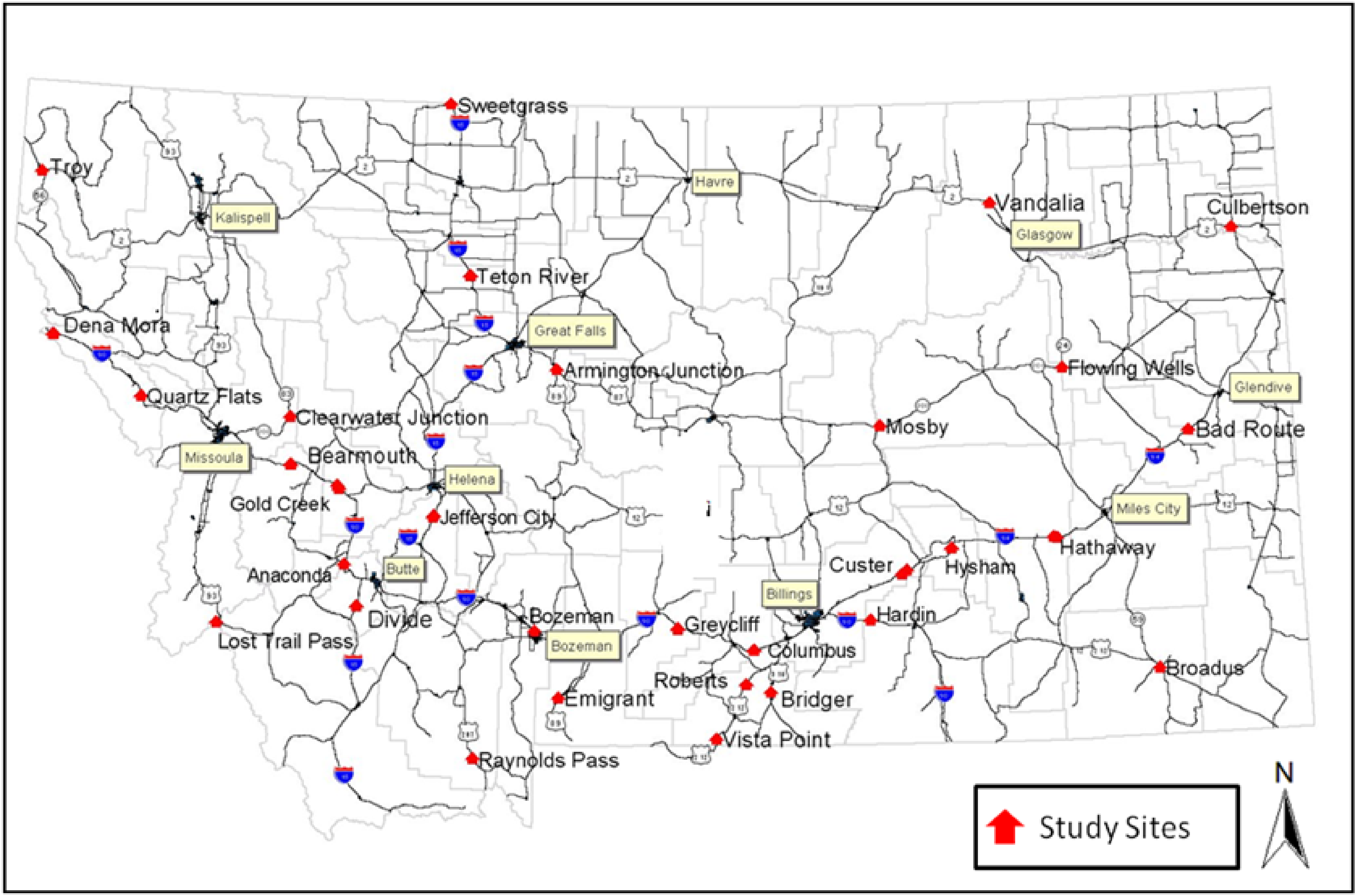

Figure 1: Map of Study Sites

Methodology

Vehicular traffic count and classification data were collected from all state-maintained rest areas in the state of Montana, with a few exceptions as discussed in the previous section. Due to the large number of study sites, it was necessary for a sampling technique to be employed in order to achieve the aforementioned plan using reasonable resources, i.e., equipment, personnel, and cost. The methodology called for collecting traffic data at representative rest areas (control stations) for the total duration of the study, not including the winter months, while collecting short-term traffic data at all other locations (coverage stations). Control station data were collected between July 16^{th} and November 25^{th}, 2009 and between April 24^{th} and September 7^{th}, 2010.

Traffic Count Field Data

Procedures

Portable traffic counters with pneumatic tubes were installed at the entrance of the rest area at each study site to obtain traffic count and classification of vehicles entering the rest areas. Using this data, along with hourly mainline counts provided by MDT, the percentage of vehicles leaving the mainline to use the rest area was estimated, as discussed later in this report.

When setting up the traffic counters, attention was paid to making sure they were set up in a way that ensured all vehicles entering the rest area would be counted. To achieve this, it was occasionally necessary to set up two counters at the same site when that site had an atypical geometry, i.e., different from the simple geometry of a single-lane entrance ramp for all rest area users. This was especially true for rest areas sharing the same site with truck weigh stations (dual use sites such as Clearwater Junction and Culbertson). Setting up the portable counters at study sites was accomplished following the procedures used in current practice. Figure 2 and Figure 3 show a typical traffic counter setup.

Figure 2: Setup Location for Sites with Typical Geometry - Gold Creek Eastbound Rest Area (Image Source - Google)

Figure 3: Pneumatic Tube Setup

Control Stations

The purpose of using control stations was to establish traffic temporal variation patterns (e.g., daily, monthly, and seasonal) at representative rest areas so that the short-term traffic counts at coverage stations could be expanded to estimate traffic counts for the duration of the study. Control stations were in operation between July 16th and November 25th, 2009, and between April 24th and August 8th, 2010. In consultation with the project technical panel, collection of traffic data at these sites was restarted after the 2009-2010 winter season to augment the amount of data collected at those stations.

Control stations were selected to represent different highway classifications and traffic levels. Interstate highways and other Major/Minor Arterial routes (mainly rural arterials) were used for highway class. Two levels of AADT were used to classify sites by traffic level on the two categories of highway classes. This resulted in four different categories of study sites. One rest area was selected from each of these categories to be a control station. The four categories of rest areas along with the selected control stations are listed in Table 14.

Table 14: Control Station Categories

Highway Group	**Average Annual Daily Traffic (AADT)**	**Study Site Selected**
Interstate high-volume	AADT≥5000	Greycliff Eastbound
Interstate low-volume	AADT<5000	Divide Southbound
Major/Minor route high-volume	AADT≥3000	Bri□ger
Major/Minor route low-volume	AADT<3000	Emigrant

For the dual sites which were on interstate highways, the rest area serving the direction with the greater traffic volumes (as provided by MDT) was selected to be the control station. The rest area in the other direction was treated as a coverage station like any other state-maintained rest area (which will be described later). Besides being representative of other rest areas in the same category of highway group and traffic level, reasonable proximity to the city of Bozeman was also considered in the selection of control stations. This was important because maintaining counter installations at control stations for long durations required periodic maintenance visits to those sites. Also, sites that have atypical traffic characteristics or geometric features were excluded from being control stations. A map of these control stations is presented in Figure 4.

Data collection at the control stations began July 16th, 2009 and ended November 25th, 2009. In an effort to estimate the seasonal variation in rest area usage throughout the peak season, traffic count data was also collected at the control stations during the summer months of 2010 (April 24th - September 7). Traffic data were collected during the overlapping period (July 16th -September 7) to estimate the change in rest area usage between 2009 and 2010.

Coverage Stations

Coverage stations consisted of all other state-maintained rest areas not selected as control stations. The counts at these stations were collected from mid-July through early-October of 2009, which was part of the peak summer season. In general, the counters were installed at these rest areas for an average of one week. At a few sites, the counters were left for longer durations as necessitated by the field data collection and travel plans. In order to obtain the data for the rest of the period, the data was expanded using derived factors from traffic counts at the control stations.

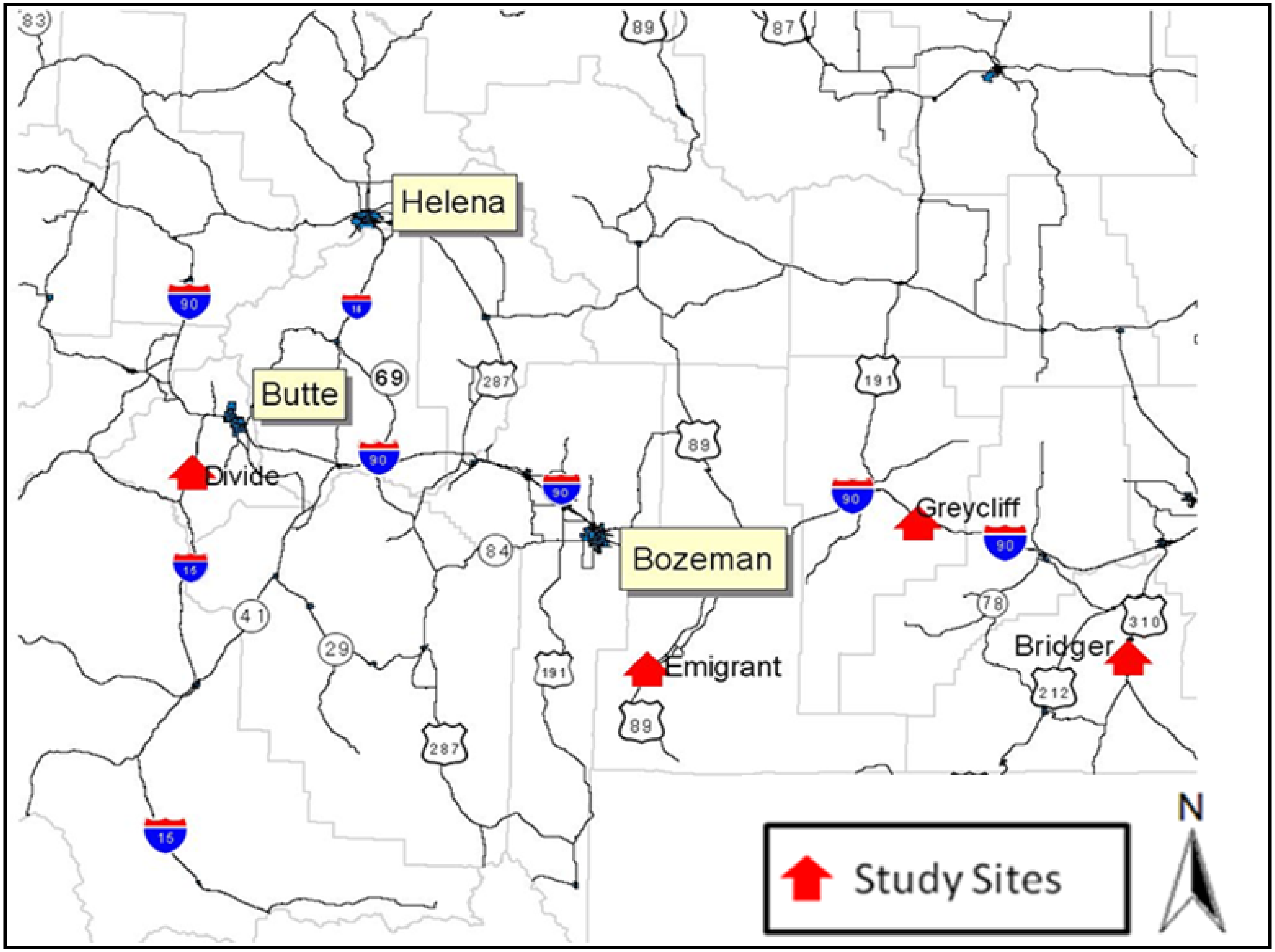

Figure 4: Map of Control Stations

Traffic Count Data Format

Each file was named by the site location. Traffic counts were provided using 15-minute intervals and included the total number of vehicles, total number of passenger vehicles (PVs), and total number of commercial vehicles (CVs) along with their percentages. Vehicles were classified by the Federal Highway Administration (FHWA) classification shown in Figure 5, which classifies passenger vehicles into classes 1 to 3, class 4 for busses, classes 5 to 7 as single unit vehicles and heavy commercial vehicles into classes 8 to 13. For this work, vehicle classes 4 – 13 were considered to be commercial vehicles. In the header of each traffic count data sheet, data collection dates and the distance to the nearest rest area and city both upstream and downstream were also included.

Figure 1

FHWA VEHICLE CLASSIFICATION

CLASS GROUP		DESCRIPTION	NO. OF AXLES
1		MOTORCYCLES	2
2		ALL CARS CARS CARS W/ 1-AXLE TRAILER CARS W/ 2-AXLE TRAILER	2 3 4
3		PICK-UPS & VANS 1 & 2 AXLE TRAILERS	2, 3, & 4
4		BUSES	2 & 3
5		2-AXLE, SINGLE UNIT	2
6		3-AXLE, SINGLE UNIT	3
7		4-AXLE, SINGLE UNIT	4
8		2-AXLE, TRACTOR, 1-AXLE TRAILER (2&1) 2-AXLE, TRACTOR, 2-AXLE TRAILER (2&2) 3-AXLE, TRACTOR, 1-AXLE TRAILER (3&1)	3 4 4
9		3-AXLE, TRACTOR, 2-AXLE TRAILER (3&2) 3-AXLE, TRUCK W/ 2-AXLE TRAILER	5 5
10		TRACTOR W/ SINGLE TRAILER	6 & 7
11		5-AXLE MULTI-TRAILER	5
12		6-AXLE MULTI-TRAILER	6
13	ANY 7 OR MORE AXLE		7 or more
14	NOT USED		
15	UNKNOWN VEHICLE TYPE		

HEAVY TRUCKS (classes 8–13)

Figure 5: FHWA Vehicle Classification System (Sarasota 2010)

Traffic Count Data Summary

Table 15 summarizes the traffic count data collected to date. In total, 840 days worth of traffic data were collected in 2009 from July 16 through November 12. 501 days of traffic data was also collected in 2010 at the four control stations from April 25 through September 7. During that time, approximately 370,000 vehicles were counted, of which 300,000 were passenger vehicles.

Table 15: Traffic Count Data Summary

Site	Control/Coverage	Dates	# Vehicles	#PV	#CV
Anaconda	Coverage	7/23-7/30	3897	3616	281
Armington	Coverage	8/7-8/14	2248	2043	205
Bad Route	Coverage	8/19-8/26	1578	1072	506
Bearmouth EB	Coverage	7/30-8/6	3988	3105	883
Bearmouth WB	Coverage	7/30-8/6	3690	2869	821
Bozeman	Coverage	9/17-9/24	4530	3930	600
Bridger	Control	7/29-11/12 2009 4/25-9/7 2010	42315	39165	3150
Broadus	Coverage	7/20-7/28	1645	1514	131
Clearwater Junction	Coverage	9/26-10/3	3045	2476	569
Columbus EB	Coverage	7/29-8/6	3881	2659	1222
Columbus WB	Coverage	8/18-8/26	2803	1950	853
Culbertson	Coverage	8/19-8/26	1289	1027	262
Custer EB	Coverage	9/19-10/1	2282	1611	671
Custer WB	Coverage	9/19-10/1	1890	1379	511
Dena Mora EB	Coverage	7/31-8/6	5563	4683	880
Dena Mora WB	Coverage	7/31-8/6	4627	3754	873
Divide NB	Coverage	9/26-10/3	1343	974	369
Divide SB	Control	7/17-11/12 2009 4/25-8/6 2010	39134	28780	10354
Dupuyer	Coverage	8/7-8/14	1338	1254	84

Table 15 Continued

Site	Control/Coverage	Dates	# Vehicles	# PC	# CV
Emigrant	Control	7/16 - 11/12 2009 4/25 - 9/7 2010	38879	36339	2540
Flowing Wells	Coverage	8/18-8/24	1146	959	187
Gold Creek EB	Coverage	7/23-7/30	4956	4429	527
Gold Creek WB	Coverage	7/23-7/30	4517	3741	776
Greycliff EB	Control	7/17-11/12 2009 4/25-8/26 2010	133780	101814	31966
Greycliff WB	Coverage	7/17-7/26	4721	3821	900
Hardin EB	Coverage	9/19-10/1	3380	2667	713
Hardin WB	Coverage	7/21-7/28	3417	2454	963
Hathaway EB	Coverage	7/20-7/28	1760	1187	573
Hathaway WB	Coverage	8/18-8/25	2045	1428	617
Hysham EB	Coverage	8/18-8/26	2250	1741	509
Hysham WB	Coverage	8/18-8/26	2269	1737	532
Jefferson City NB	Coverage	7/23-7/30	869	708	161
Jefferson City SB	Coverage	7/23-7/30	901	680	221
Locate	Coverage	7/20-7/28	301	123	178
Lost Trail Pass	Coverage	8/13-9/26	7614	7208	406
Mosby	Coverage	8/18-8/25	1218	1058	160
Quartz Flats EB	Coverage	7/31-8/6	4569	3761	808
Quartz Flats WB	Coverage	7/31-8/6	3505	2881	624
Raynolds Pass	Coverage	7/23-8/7	2875	2518	357
Roberts	Coverage	7/29-8/6	1622	990	632
Sweetgrass	Coverage	8/7-8/14	1976	1425	551
Teton NB	Coverage	8/7-8/14	1440	1351	89
Teton SB	Coverage	8/7-8/14	1413	1256	157
Troy	Coverage	7/31-8/6	3727	3386	341
Vandalia	Coverage	8/18-8/25	820	704	116
Vista Point	Coverage	7/29-8/6	2850	1787	1063
Totals		**1341 days**	**369906**	**300014**	**69892**

PV = Passenger Vehicles
CV = Commercial Vehicles

Challenges

Several challenges were encountered when collecting traffic count data, requiring the re-collection of data from several of the sites for various reasons. The approaches employed in addressing these challenges varied and are discussed in the following portions of this section. A common problem was punctured tubes; consequently, axle hits would not force the air pulse to travel to the counter. A photograph illustrating this problem is presented in Figure 6.

Figure 6: Photo of Punctured Tube

Occasionally, the nails in the pavement or the strapping used to hold down the tubes pulled up. This likely affected the accuracy of vehicle count and classification data at the site of interest. When a vehicle hit the tube, the tube would bounce and impact the pavement, potentially causing the traffic counter to record multiple axle hits. Each of these challenges was addressed by performing equipment fixes and recollecting the data.

Another scenario occurred when the counter itself did not function properly. For example, the first set of data collected at the Custer eastbound site revealed that the majority of vehicles that stopped at the rest area were motorcycles, which was not consistent with what was observed in other rest area data. Other errors involved data where the counter either recorded a high percentage of unclassified vehicles, or the counter simply did not work properly (power loss). In one instance, the counter failed completely (hardware failure). Regardless of the cause, these challenges were addressed by employing a different counter to recollect data at the site.

Other challenges arose at stations with atypical geometry. For example, a common wide access (driveway) to the rest area makes it very difficult to obtain accurate traffic counts and classification using the driveway access location. At such sites, two counters were set up: one for truck traffic and one for passenger vehicle traffic when the two traffic streams split. An example illustrating this is shown in Figure 7.

At some dual-use sites, it was not possible to count the truck traffic without counting all of the trucks entering a weigh station because the rest area truck parking could only be accessed by traveling through the weigh station. For such sites, the researchers obtained the counts and hours of operation for the weigh station from MDT's Motor Carrier Services Division in order to determine the count of trucks only using the rest area, i.e., when the weigh station was not in service.

Figure 7: Atypical Geometry Layout – Armington Rest Area (Counter Locations Circled)
Image source: Google

Another concern was the accuracy of data that was collected at the control station later in the fall, as freezing temperatures may affect the pneumatic tube counters. Additionally, early winter weather events resulted in missing data because of snow and icy weather. When it snowed, MDT plows were dispatched to clear the mainlines as well as the entrances to rest areas. The plows tore up the pneumatic tubes, rendering the counters unable to collect vehicle counts. This caused data to be lost from the time the tubes were torn up until they were replaced. Given the unpredictability of Montana weather, this could require a lot of travelling to continue collecting data at these sites throughout the winter. Consequently, the final control station re-installations occurred on Tuesday, November 10. The control stations were removed for the season on Wednesday, November 25. No weather-related issues were encountered during the 2010 control station counts.

Door Counter Data Provided by MDT

Under the project work plan, MDT was responsible for the installation of automatic door counters at every state-maintained rest area in Montana investigated by this project. In conjunction with water usage data, data from the door counters would help MDT better design and maintain rest areas in the future, primarily in terms of designing water and wastewater treatment systems and determining the required number of stalls for a specific restroom. This would be accomplished through an understanding of the relationship between the number of persons entering a restroom and the amount of wastewater generated.

MDT personnel in charge of maintaining the rest areas recorded and reset the door counters each morning between 6:00 a.m. and 8:00 a.m., entering data into a spreadsheet with daily counts for persons entering and exiting the rest area restrooms. As the counters provided counts for patrons both entering and exiting, the counts recorded were divided by two to obtain the number of persons using the restroom facilities.

Challenges

Being unfamiliar with the door counter devices, the research team had some concerns about the accuracy of the counters in recording the number of patrons accessing or leaving the rest area and the likelihood of malfunctions in the field. While malfunctions could not be addressed by the researchers, validations of the counts collected by the door counters were completed, using the data patron door counts discussed previously. Counter malfunctions were identified through manual examination of the data and removed from subsequent analysis. Aside from this, little could be done by the researchers to address counter problems, as the devices were maintained by MDT personnel.

Patron-Door Counter Correlation Data

Patron door count data, which measures restroom use, was collected manually to determine whether the counts recorded by the door counters need to be adjusted. Recorded door counts may have required adjustment because more than one patron could enter the restroom simultaneously, an event which may be counted as a single patron due to the nature of how the recording device employed functioned (infrared beam). Estimating the number of people using the rest area building is critical in determining building size requirements, restroom stall requirements, water usage, and sewage system requirements.

Overview of Study Sites

The sites selected for the manual patron counts were Greycliff eastbound, Divide southbound, Anaconda, and Bozeman. These sites were selected because two of the sites (Anaconda and Bozeman) were single entry sites that have a main multi-use building where visitors enter. The other two sites (Greycliff eastbound and Divide southbound) were selected as they had separate entrances for the men's and women's restrooms. Collectively, these sites represented the various door counter conditions that existed at rest areas statewide. Rest area location (proximity to Bozeman) was also a consideration in the selection of study sites. Two of these sites were control stations, so the condition of permanent traffic counters could be checked at the same time. A map showing the sites selected for this study is presented in Figure 8.

Field Data Collection Procedure

Manual counts were collected by observing the patrons entering and exiting the rest area building and comparing the counts to those recorded by the automatic door counter. A simple form was prepared and used in conducting the field observational study. The information consisted of site name, the date, the times during the day, and the number of patrons entering/exiting. Patrons entering the facility were marked with an “E,” patrons exiting the facility were marked with an “X.” The average amount of time spent collecting counts at each site was approximately four hours, with the data aggregated into 15-minute intervals. An example of the form used in data collection is shown in Figure 9.

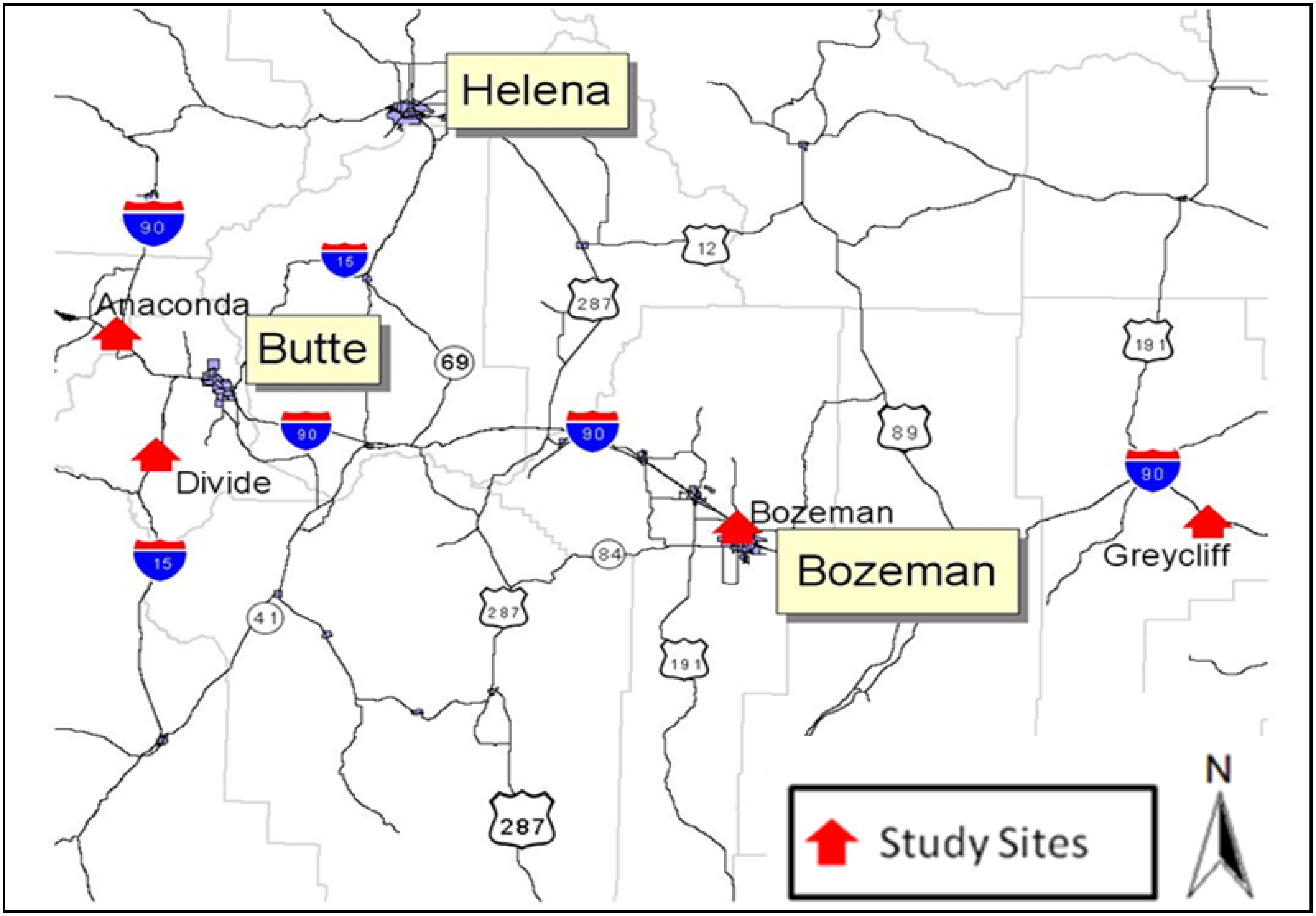

Figure 8: Manual Patron Count Validation Sites

Site:			**Date:**	
Interval Start Time	**Interval End Time**	**Personal Observations**	**Door Counter Observations**	**Ratio**

Figure 9: Sample Manual Patron Count Collection Form

<u>Patron-Door Counter Data Summary</u>

Presented in Table 16 is a summary of the manual calibration counts completed during the course of this research. Approximately 15.5 hours of personal observations were made in the field over the span of four non-consecutive days, resulting in 1,070 individual observations. The observations conducted in the field showed the automatic door counters are accurate to within 10 percent of observed entries and exits. Consequently, it was determined reasonable to divide the data reported by MDT site maintenance by two in order to establish the number of patrons using a restroom.

Table 16: Patron–Door Counter Data Summary

Site	Facility type (single or dual)	Dates Collected	Time Interval Collected	No. of Personal Observations
Anaconda	Dual	October 16	12:15 p.m.–4:15 p.m.	230
Bozeman	Dual	September 25	9:15 a.m.–12:30 p.m.	498
Divide SB	Single	October 8	11:30 a.m.–5:00 p.m.	155
Greycliff EB	Single	October 3	1:15 p.m.–4:00 p.m.	187

Water Usage Data Provided by MDT

As per the project work plan, MDT's Planning Systems Data and Statistics Bureau was responsible for the installation of water meters at all state-maintained rest areas investigated by this project. This data was employed in estimating the amount of water used and wastewater being produced at each rest area. The estimation of the latter is based on the assumption that the amount of water used is approximately equal to the amount of wastewater produced, which has been found by previous research. MDT rest area maintenance personnel recorded water meter readings in a spreadsheet of water usage in gallons per day at each site.

Chapter Summary

This chapter has summarized the data collection processes employed and completed during this project. This research involved all state-maintained rest areas in Montana, except for the Dearborn, Dupuyer and Locate rest area facilities.

Traffic counts were collected at all study sites using automatic traffic counters. This required a sampling technique due to the lack of available equipment for the large number of study sites. The technique involved selection of control stations for which data was collected throughout the duration of the project, except during the winter season of 2009-2010. The sites not selected as control stations were considered coverage stations. Data for these sites was collected for an average of one week but not less than six days.

Automatic door counters were installed by MDT personnel at all study sites. On-site validation observations were also conducted at Greycliff eastbound, Bozeman, Anaconda, and Divide southbound to determine whether the counts recorded by the counters needed adjustment. These sites were selected because two had one entrance to the facility (Anaconda and Bozeman), while the other two had separate entrances for the men's and women's facilities (Greycliff and Divide). The observations conducted in the field showed the automatic door counters are accurate to within 10 percent of observed entries and exits. Consequently, it was determined reasonable to divide the data reported by MDT site maintenance by two in order to establish the number of patrons using a restroom.

Water meters were installed by MDT at all study sites, with a few exceptions. The water usage data were collected to estimate the wastewater generated at each site, with the assumption that the water used (i.e. clean water) was approximately equal to the wastewater generated at a rest area. Using rest area traffic counts in conjunction with door counts and water meter data, factors were calculated for amount of water used/wastewater generated per person, and will be discussed later in this report.

DATA ANALYSIS

This chapter discusses the procedures and results of the various analyses performed on the data collected during this project: traffic data and water/door counter data. The procedures used to process the data for analysis are also presented in detail. Analysis of the traffic data involved review and summary of the general characteristics of the data categorically, as well as detailed statistical analyses, namely correlation and linear regression techniques. The analysis of the dwell time data included the development of descriptive statistics and the comparison of different variables that could affect this aspect of rest area planning and design. However, the results of this analysis are not included in this thesis because the author was not involved in the analysis of the dwell time data. Water usage/door counter data analysis included the development of descriptive statistics for water use per patron, as well as identifying seasonal variations of the data.

Traffic Data Analysis

The following sections discuss the analysis of the traffic data collected throughout the course of this project. At the highest level, the traffic data was broken down by rest area category (high-volume interstate, low-volume arterial, etc.). The following sections also present a summary of the various types of analyses conducted on the traffic data, including general descriptive statistics, correlation analysis, and linear regression analysis.

Data Processing

Due to the nature of the data collection process, some traffic counts needed to be estimated due to the various counter malfunctions at control sites discussed previously[3]. A linear interpolation process was used to estimate missing counts. In this process, data from before and after the period of counter malfunctioning at a site were used to interpolate the missing data. This interpolation was based on observed trends for the same day of week and time of day for which data was missing.

When automatic traffic recorders (ATR) were located on the same mainline facility and no "branching[4]" facilities were located between the location of the ATR and the rest area, hourly mainline counts from the permanent ATR's were used during the period in which rest area traffic data was collected. The ATR's associated with each of the permanent count stations for the different facility types employed in this research are presented in Table 17. When these counts were not available, 36-hour sample counts provided by MDT were expanded to estimate the hourly mainline traffic counts during the period of rest area traffic data collection. The source of traffic data for each site is presented in Table 18. Some of these sample counts were associated with a different day of the week or were collected during a previous year, requiring adjustment factors to be applied to bring the count to the necessary present day and/or year. Daily and monthly factors were derived using trends observed from ATRs selected to represent all other

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[3] Note that estimation of missing counts was made only for control stations, as sample stations were simply recollected when a malfunction occurred.

[4] A "branching" facility would be a case where a major route split off or intersected the rest area route of interest.

sample count stations to expand the one day counts. If a sample count was collected during a different year, yearly adjustment factors provided by MDT were employed to estimate the 2009 counts. These sites were selected using a process similar to that employed in selecting the control stations based on the mainline annual average daily traffic (AADT) and facility type, discussed in the previous chapter. Directional splits of traffic for each ATR were obtained from MDT data.

Table 17: Representative ATRs for Expanding Mainline Sample Counts

Facility Type	**AADT category**	**Representative ATR**
Interstate	High-volume	A-124
Interstate	Low-Volume	A-61
Arterial	High-Volume	A-107
Arterial	Low-Volume	A-46
Arterial	Low-Volume(NE corner)	A-10

Table 18: Hourly Mainline Count Data Source

Site	Mainline Traffic Data Source
Anaconda	36 hour
Armington	2 approaches ATR
Bad Route	36 hour
Bearmouth	36 hour*
Bozeman	36 hour
Bridger	36 hour
Broadus	36 hour
Clearwater Junction	2 approaches ATR
Columbus	ATR*
Culbertson	36 hour
Custer	ATR*
Dena Mora	36 hour*
Divide	ATR*
Emigrant	ATR*
Flowing Wells	36 hour
Gold Creek	36 hour*
Greycliff	ATR*
Hardin	36 hour*
Hathaway	ATR*
Hysham	36 hour*
Jefferson City	36 hour*
Lost Trail Pass	36 hour
Mosby	36 hour
Quartz Flats	ATR*
Raynolds Pass	ATR*
Roberts	ATR
Sweetgrass	36 hour
Teton	36 hour*
Troy	36 hour for all approaches
Vandalia	36 hour
Vista Point	36 hour
* Dual rest area site	

The proportion of vehicles exiting the mainline and entering the rest area was estimated by dividing the number of vehicles entering the rest area by the mainline traffic count every hour. For sites with multiple mainlines, such as those located at T-intersections of highways (Clearwater Junction, Armington, Flowing Wells, Lost Trail

Pass, and Troy), the mainline traffic counts from all three directions were added together and the resulting traffic count divided by two based on the assumption that each vehicle would enter and leave the intersection once. All hourly mainline counts and AADT values at these sites were rounded up to the next highest integer, especially for low-volume sites such as Flowing Wells. Also, any percentages that were found to be greater than 100 percent were reduced to 100 percent, as it was not possible for more traffic to enter the rest area than had been observed by the data provided by MDT. Such instances occurred during nighttime hours at the Flowing Wells, Mosby, and Lost Trail Pass sites (low volume arterial category), on routes with extremely low traffic volumes (single digit vehicle counts per hour during late night hours), as recorded by MDT. In the case of rest areas along such routes, data would sometimes indicate that the number of vehicles observed entering the rest area exceeded that recorded during a corresponding hour previously counted by MDT. In total, a total of only twelve individual hours between the three sites experienced such an occurrence. Consequently, the adjustment of the entering volumes was not likely to affect the overall analysis.

Missing data specific to the Emigrant counter placed at the south entrance of the rest area (dated 9/2/2009 through 9/21/2009) was estimated using count data from the opposite counter placed at the north entrance. To accomplish this, the two weeks before and after the period of the missing count data were used to find the average ratio of traffic measured between the south entrance and north entrance counters (found to be 1.12). The north counter readings were then multiplied by this factor to estimate the missing readings for the south entrance counter.

The missing data from the Greycliff EB site (dated 9/18/2009 and 9/27/2009 through 10/1/2009) were estimated by fitting a line to the data ($y = -3.6799x + 782.94$). This same process was used to estimate the missing days at Bridger (7/17/2009 through 7/28/2009 and 10/1/2009), with the line fitting the data being $y = -0.9618x + 227.3$.

For any days in which actual traffic counts collected by the research team were only collected for a portion of the day, the missing hours of count data were estimated using the average number of vehicles during the missing time period from the other days of data collection. For example, if a site was missing data from the hours between 6 p.m.to midnight, the average count during those hours from the other days of data collection (for example, six full days) at that site was determined and used to complete the partial day.

Characterization of Rest Area Usage

The following sections characterize various aspects of rest area usage by the different highway classifications and traffic levels employed by this research: high and low-volume Interstates and high and low volume Major/Minor Arterial routes. In characterizing rest area usage, four distance variables were considered for analysis: distance to the nearest upstream rest area, distance to the nearest upstream city with 24/7 facilities, distance to the nearest downstream rest area, and distance to the nearest downstream city with 24/7 facilities. It was expected that as each of these distances for a specific rest area increased, the usage of that specific rest area would increase accordingly. Other variables examined in characterizing rest area usage included the condition of the rest area facility, the proportion of truck traffic entering the rest area, the presence of a visitor information center, and the presence of a weigh station in operation adjacent to the rest area facility. The rest area usage is expressed in percent of the hourly split of mainline AADT entering the rest area.

<u>High-Volume Interstate</u>

This category includes all rest areas located on Interstate highways with an average annual daily traffic (AADT) equal or greater than 5000 vehicles per day according to 2009 MDT data. Eighteen rest areas fell into this category: Anaconda, Bearmouth eastbound and westbound (EB and WB), Bozeman, Columbus EB and WB, Dena Mora EB and WB, Gold Creek EB and WB, Greycliff EB and WB, Hardin EB and WB, Jefferson City northbound and southbound (NB and SB), and Quartz Flats EB and WB. This category was comprised of the largest number of sites, and consequently, the greatest quantity of field data collected.

Table 19 presents the descriptive statistics for the high-volume interstate category. The average usage based on observed entering traffic was approximately 10 percent. The median usage was approximately 9.1 percent, while the mode was approximately 9 percent. The standard deviation was approximately 6.5 percent, suggesting a high variation in the percent usage observations. This was likely due to the fact that rest area usage varies over time at a particular site and also varies across different rest areas in general. The percent usage ranged between zero and 50 percent across all sites in this category. The 85^{th}, 90^{th}, and 95^{th} percentiles approximately ranged between 15 to 22 percent.

Table 19: High-Volume Interstate Rest Areas: Frequency of Usage

Mean	9.92%
Median	9.09%
Mode	9%
Standard Deviation	6.40%
Range	0-50%
85th percentile	15.58%
90th percentile	18.11%
95th percentile	22.55%

Figure 10 and Figure 11 display the frequency histogram and the cumulative frequency curve of rest area usage at high-volume interstate highway sites. Examination of Figure 10 confirms that higher usage frequencies are associated with rest area usage rates of between 8 and 13 percent of traffic entering.

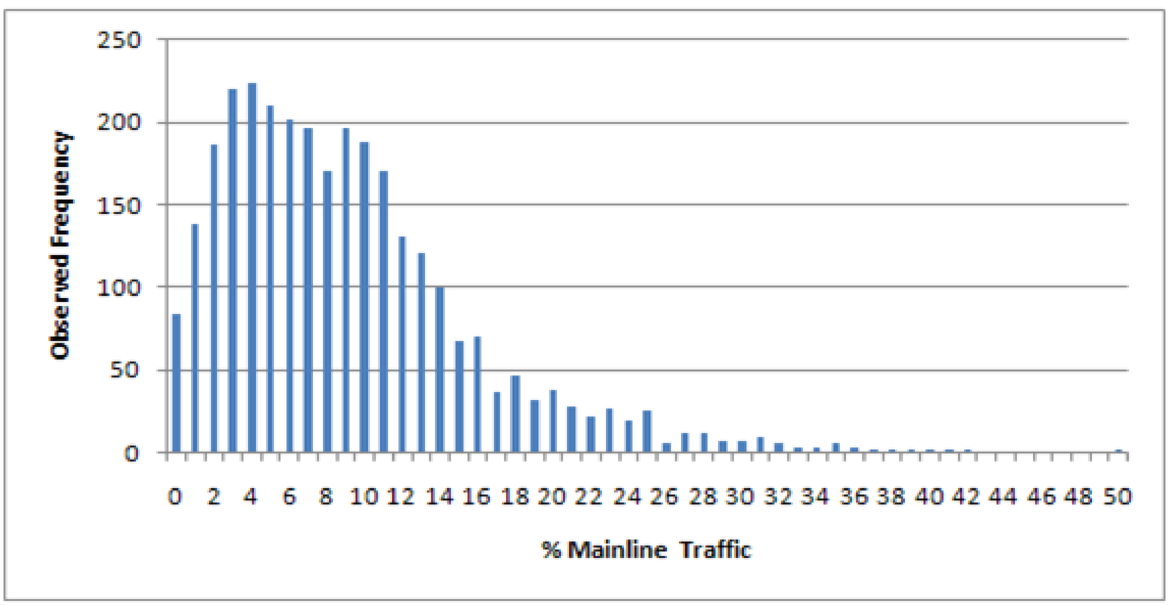


Figure 10: High-Volume Interstate Rest Areas: Frequency of Use Histogram

The cumulative frequency curve presented in Figure 11 somewhat resembles the S-shape curve that could be expected based on the bell-shaped distribution exhibited by the histogram in Figure 10. Nearly all values of the percentage of mainline traffic entering the rest area fell at or below 40 percent.

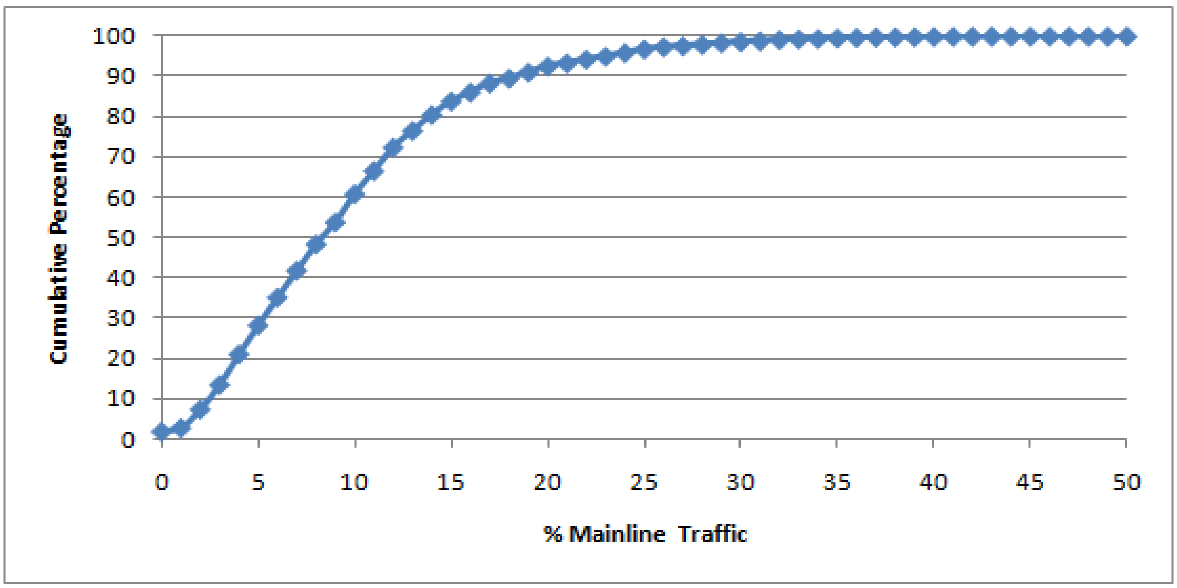


Figure 11: High-Volume Interstate Rest Areas: Cumulative Frequency of Use Curve

To gain better insights into the relationship between the rest area usage and study variables, scatter plots were established for trends that could be discerned from the graphs. Based on an examination of Figure 12, it appears that as the percentage of trucks in mainline traffic increased, rest usage increased. Note that the classes used in examining trucks (i.e. commercial vehicles) were FHWA types 5 through 13. This is consistent with expectations, as trucks may need to use rest areas more often, since they are more involved in long trips. Additionally, one would expect that routes with higher traffic volumes would also contain a higher volume of trucks, resulting in a correspondingly larger proportion of these vehicles stopping at a rest area.

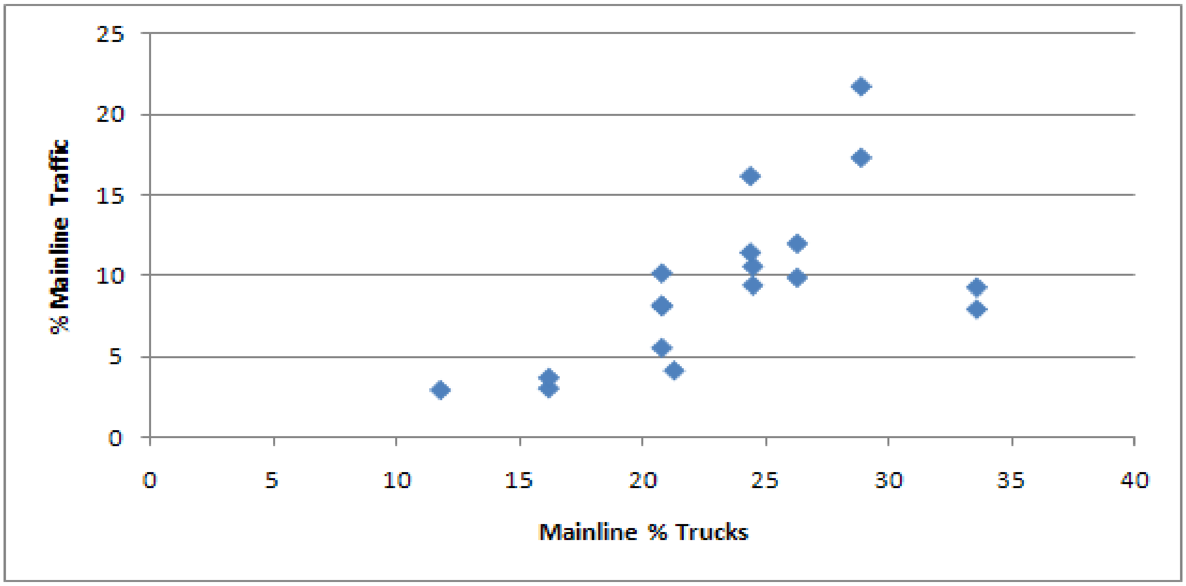


Figure 12: High-Volume Interstate Rest Areas: Truck Proportion vs. Rest Area Usage

As stated earlier, four distance variables were taken into consideration during the descriptive analyses. These included:

- Nearest upstream rest area – the distance to the nearest upstream rest area facility in miles
- Nearest upstream city - the distance to the nearest upstream city providing basic services 24/7 including parking and restrooms in miles
- Nearest downstream rest area – the distance to the nearest downstream rest area facility in miles
- Nearest downstream city - the distance to the nearest downstream city providing basic services 24/7 including parking and restrooms in miles

Figure 13 presents the relationships between the rest area usage and the four distance variables. A visual inspection of the four scatter plots presented in this figure revealed no discernable trends or relationships between distance and rest area usage. Again, one would expect that as the distance to the nearest rest area or city increased, so too would rest area usage; however, such a relationship is not completely apparent in any of the scatter plots.

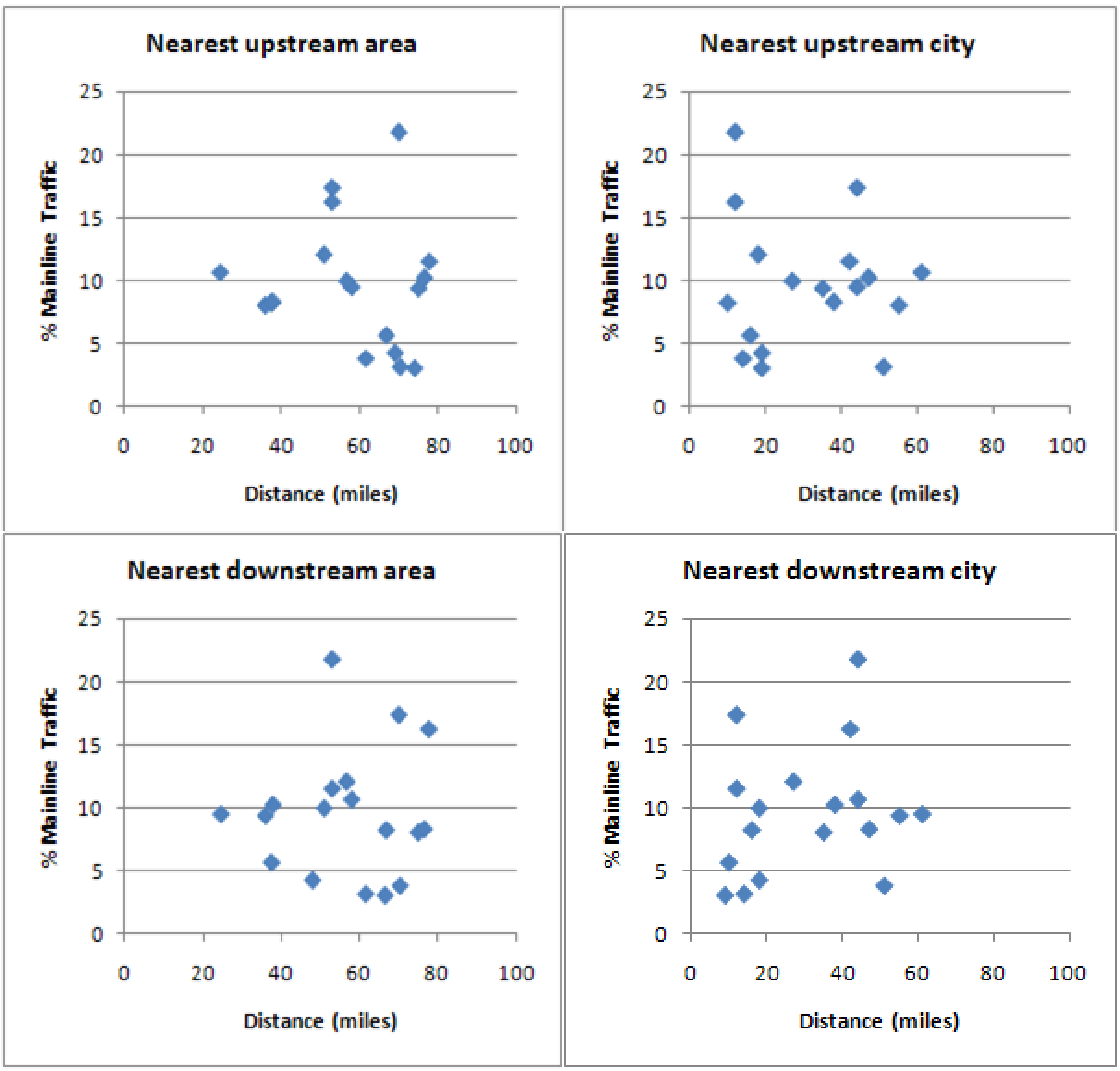


Figure 13: Plots of Distance Variables vs. Rest Area Usage

The relationship between rest area usage and the overall condition of rest area facility is shown in Figure 14. Condition ratings were provided by Chris Dorrington, Transportation Planning Manager for MDT. Ten of the eighteen rest area sites were given a condition rating of “poor”, four were given a “fair”, and four were given a rating of “good”. The bar chart in this figure illustrates that rest area facilities in good overall condition were associated with slightly higher rest area usage. This relationship is consistent with expectations, although the similar usage percentages for the poor and fair categories would suggest that usage is not strongly driven by condition. One explanation is that most rest area patrons are unlikely to know the condition of a rest area prior to arrival, and therefore, will not make their decision to stop based site condition.

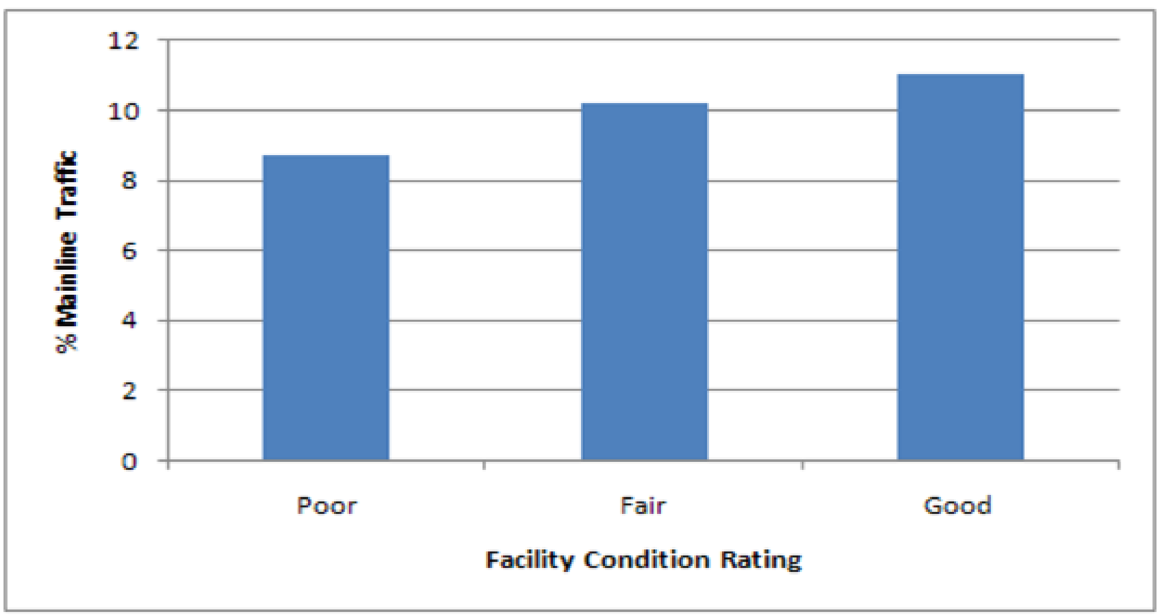


Figure 14: High-Volume Interstate Rest Areas: Condition Rating vs. Rest Area Usage

Figure 15 illustrates the hourly variation in rest area usage throughout the day. Two measures of rest area usage were plotted in this figure: the percent mainline traffic entering the rest area and the actual counts of vehicles entering the rest area. The two measures exhibit different trends. The percent mainline traffic measure produces two daily peak periods: the first between midnight and 3:00 a.m. and the second at midday between 10:00 a.m. and 3:00 p.m. The actual count measure has only one peak period, occurring mid-day between 10:00 a.m. and 3:00 p.m. While the percentage of mainline traffic using the rest area during the night is relatively high, the corresponding counts are among the lowest during the night and therefore have less significance in the planning and design of rest areas.

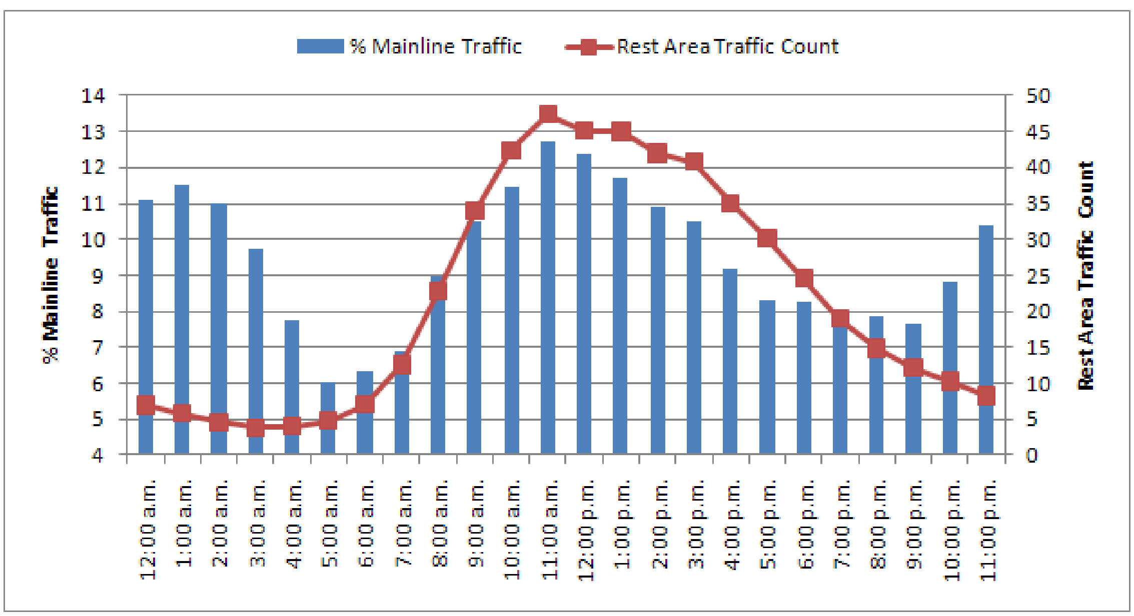


Figure 15: High-Volume Interstate Rest Areas: Daily Distribution of Rest Area Usage

The weekly variation in rest area usage by day of week is presented in Figure 16. As this figure illustrates, usage climbs until approximately midweek, falls slightly, then increases on Saturday and drops on Sunday. This may be partly attributed to the fact that a higher proportion of non-local traffic is more likely to use the rest areas during weekends compared with regular drivers who constitute a higher proportion of traffic during weekdays. It should be noted that variation in rest area usage during the week is relatively small, as the averages range between 9.4 percent on Monday and 10.6 percent on Wednesday, suggesting that usage is fairly consistent from day to day.

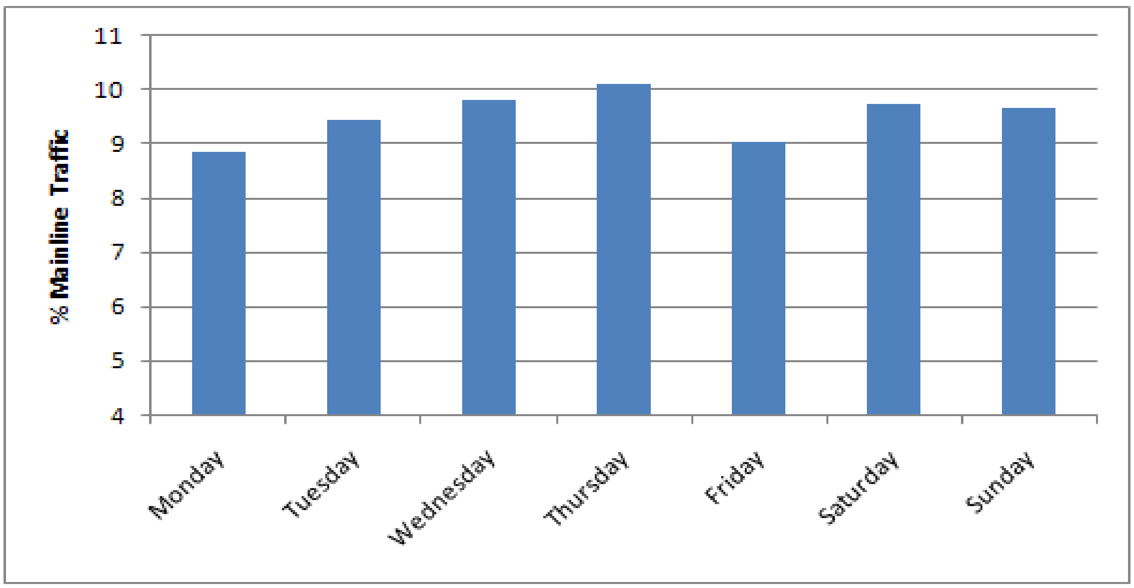


Figure 16: High-Volume Interstate Rest Areas: Weekly Distribution of Rest Area Usage

In order to compare the percent rest area usage by time of season, weekly averages of the percent usage at the control station for the group were calculated and plotted. A day in the middle of the week was used as the representative data for the weekly averages. To make comparisons between years easier, corresponding dates for each year were employed, resulting in Wednesdays being used as the average day in 2009 and Thursdays in 2010.

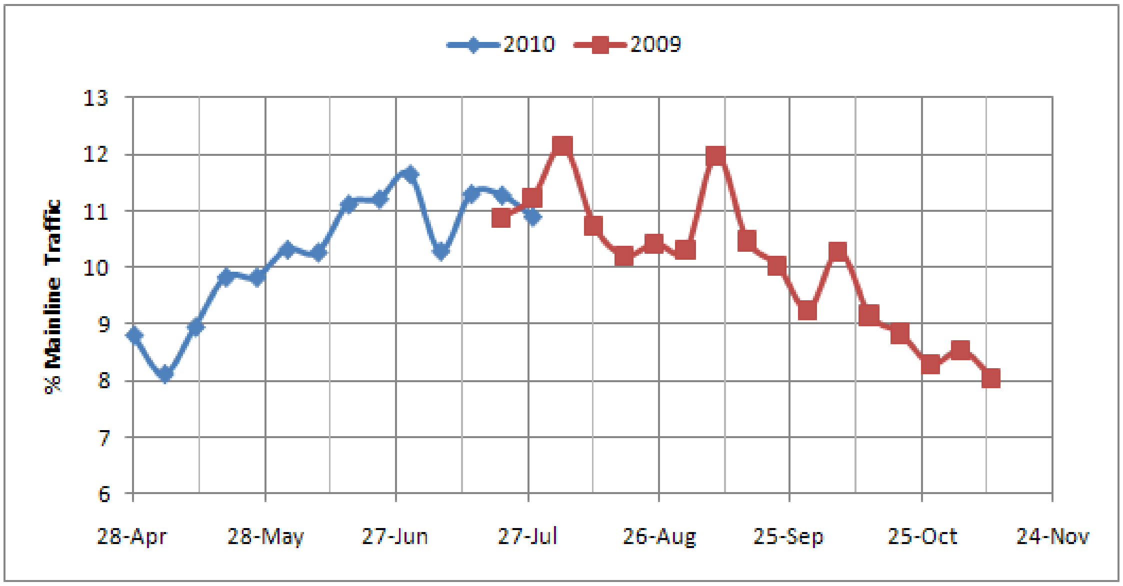


Figure 17: High-Volume Interstate Rest Areas: Greycliff EB Seasonal Rest Area Usage

Prior to traffic data analysis, it was hypothesized that the percent usage at rest areas would be higher during the summer months compared to other time periods. Examination of Figure 17 shows that this pattern does indeed occur. Rest area usage climbs gradually beginning in May, peaking during the summer months and decreasing at the end of August. Interestingly, some decline is also observed during the summer peak, occurring around late-June. The cause of this decline is not immediately clear.

Low-Volume Interstate

The low volume interstate category included all rest areas on Interstate highways with an AADT of less than 5000 vehicles per day. Twelve sites were included in this category: Bad Route, Custer Eastbound and Westbound (EB and WB), Divide Northbound and Southbound (NB and SB), Hathaway EB and WB, Hysham EB and WB, Sweetgrass, and Teton NB and SB.

Table 20 presents the general descriptive statistics for this category. The average percent mainline traffic entering the rest area was approximately 8.7 percent, slightly lower than the average for the high-volume interstate category. The percentiles are also significantly lower than those for the high-volume interstate category, as was expected. The standard deviation was approximately 7 percent, which was slightly lower than that for the high volume interstate category, although still very high. Again, the two types of variation within the data may explain this high deviation: the variability between rest areas as well as the existence of hourly variation within a single rest area.

Table 20: Low-Volume Interstate Rest Areas: Frequency of Use

Mean	8.69%
Median	7.69%
Mode	8%
Standard Deviation	7.21%
85^{th} percentile	13.76%
90^{th} percentile	15.68%
95^{th} percentile	19.03%
Range	0-100%

Figure 18 and Figure 19 present the frequency histogram and cumulative frequency curve for the low-volume Interstate category. The histogram suggests a positively skewed bell-shaped distribution excluding the zero values.

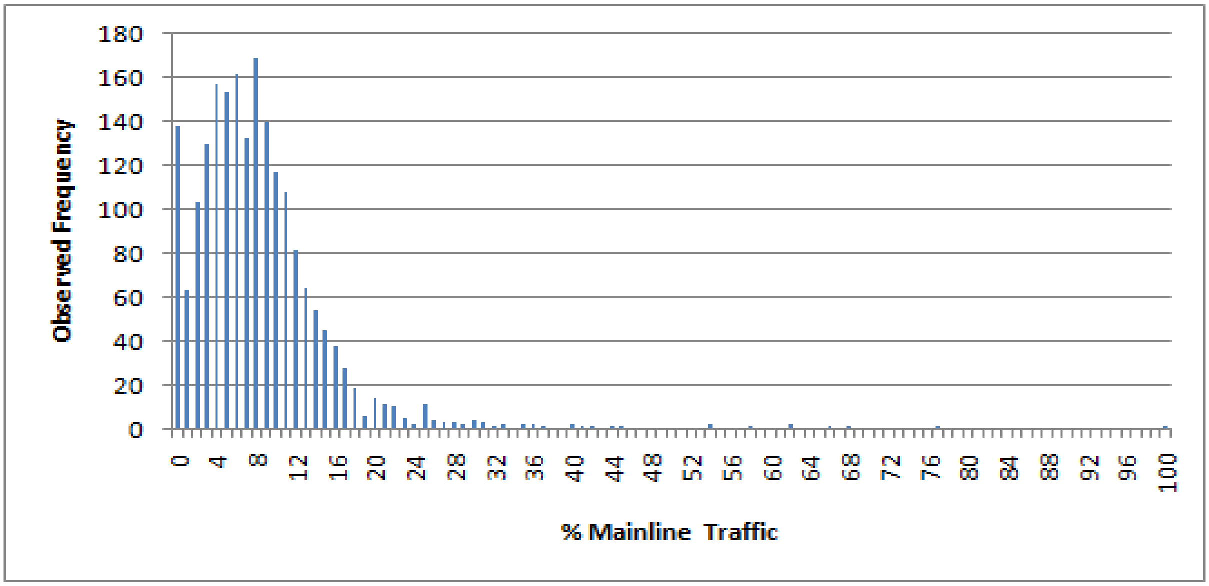


Figure 18: Low-Volume Interstate Rest Areas: Frequency Histogram

The cumulative frequency curve in Figure 19 exhibits the general S-shape associated with a normal distribution. Most values were at or below 20% usage, with the top portion of the plot flattening out. This shape appears similar to that found at the high volume interstate highway category, with the exception of the percentage of mainline traffic entering the rest area peaking at 20 percent compared to 40 percent for the high-volume category.

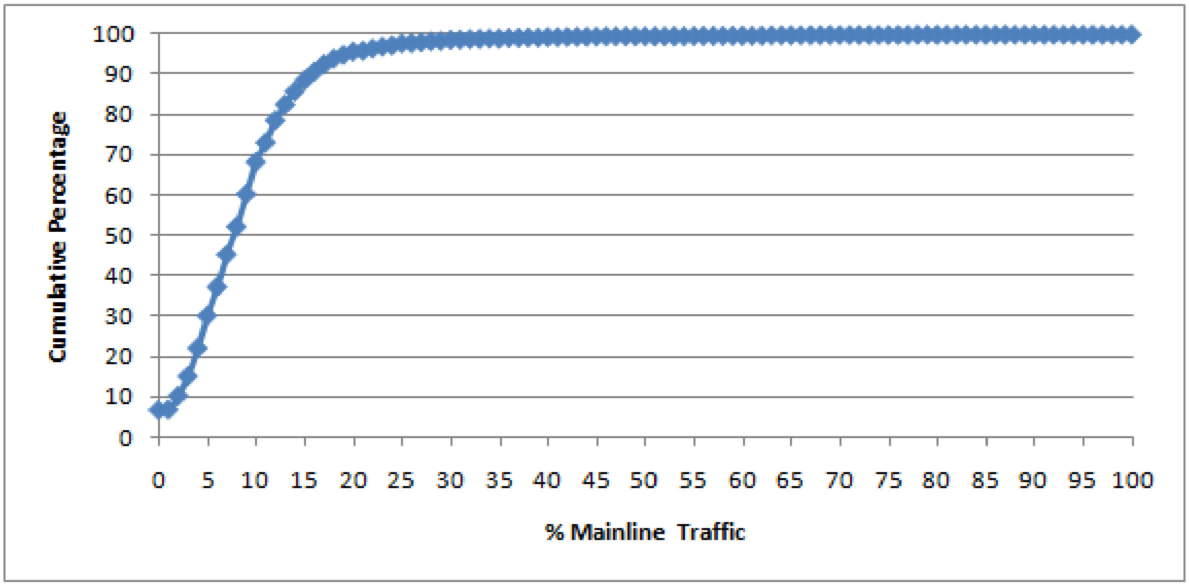


Figure 19: Low-Volume Interstate Rest Areas: Cumulative Frequency Curve

The proportion of mainline truck traffic entering the rest areas indicates a slightly negative correlation with the percentage of rest area usage, as shown in Figure 20. This differs from what was observed for the high-volume Interstate category. Intuitively, one would suspect that as mainline traffic increased, so too would the proportion of trucks entering the rest area. However, in this case, it was observed that higher percentages of trucks entered rest areas at sites where lower overall percentages of mainline traffic used the site. The reason for this is not entirely clear, although perhaps the sites toward the right of the figure were located along routes where fewer services were available, resulting in truck drivers taking advantage of the opportunity to use a rest area.

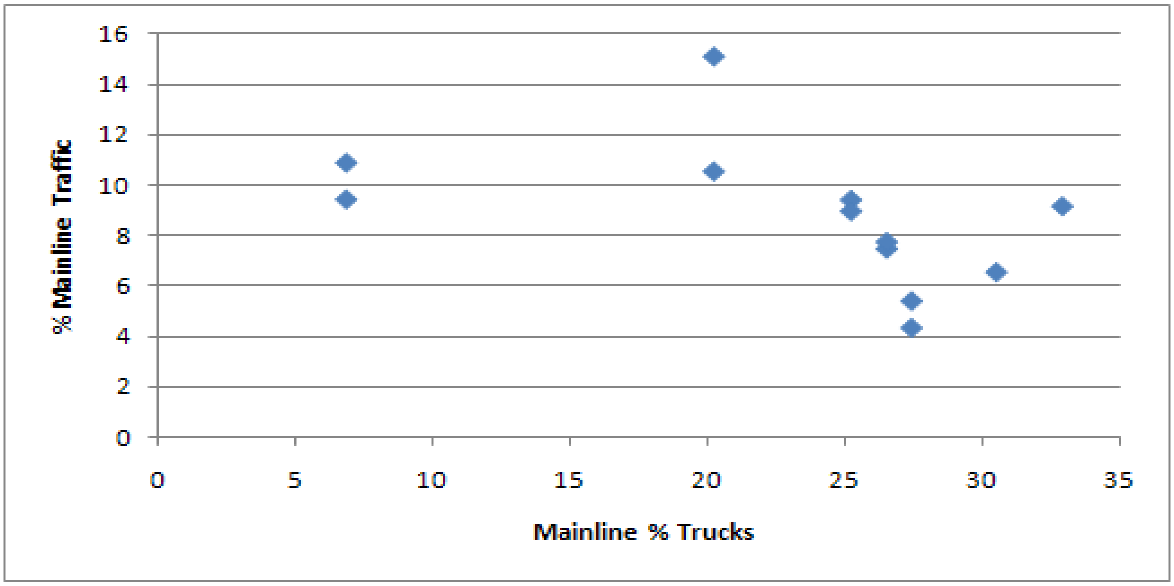


Figure 20: Low-Volume Interstate Rest Areas: Truck Proportion vs. Rest Area Usage

The nearest rest area variables show a logical correlation with rest area usage, while the nearest city variables exhibit an illogical inverse relationship. All correlations between distance variables and rest area usage were found to be weak. Examination of Figure 21 suggests no distinct relationship existed between the distance variables used and rest area usage. A similar observation was found for the high-volume Interstate category.

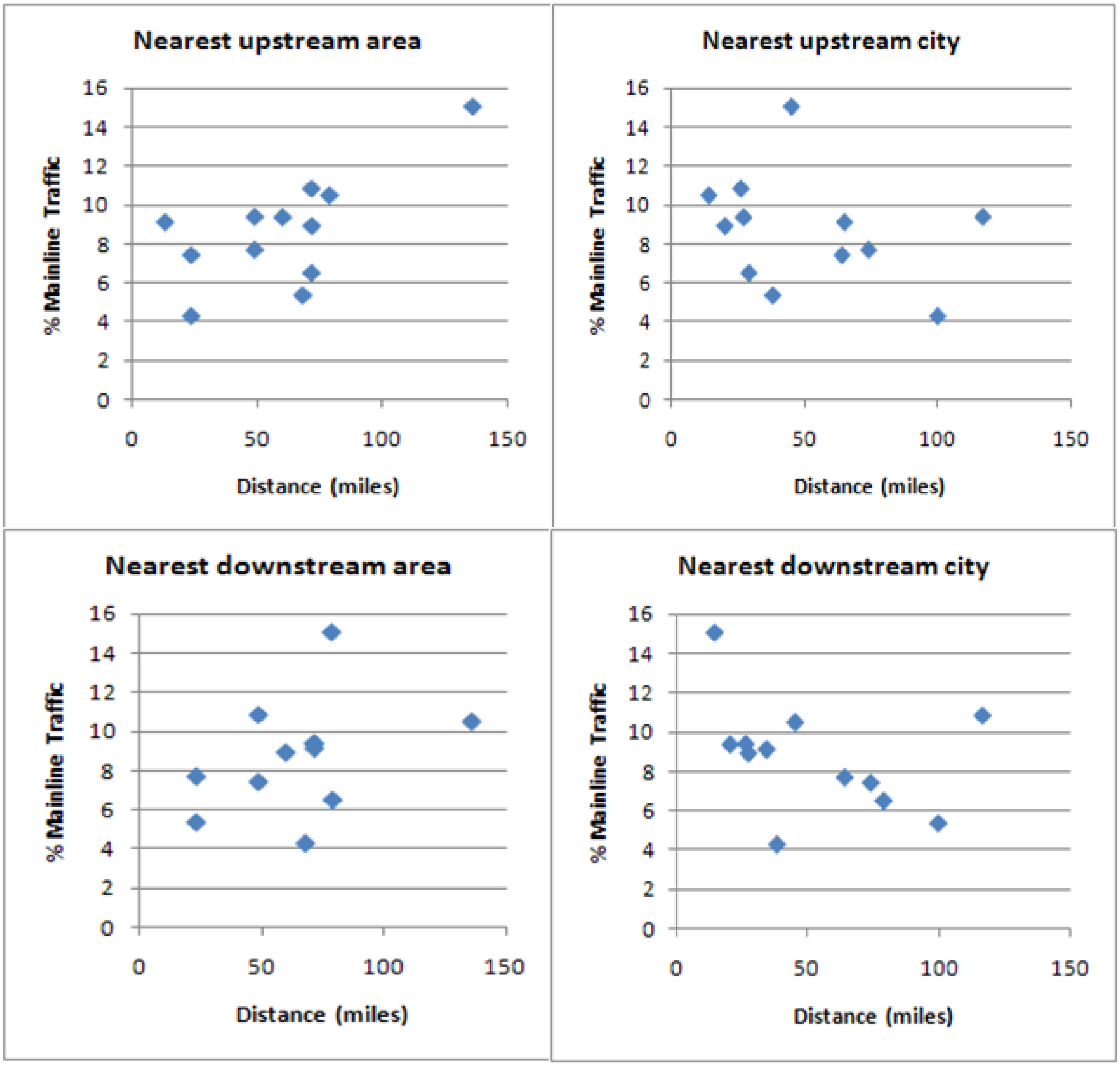


Figure 21: Low Volume Interstate Rest Areas: Plots of Distance Variables vs. Rest Area Usage

Figure 22 presents the relationship between the overall condition of the rest areas and the usage. Rest areas on low volume interstates exhibited a decrease in usage when the general condition rating improved, which is contrary to expectations. However, only two sites in this category (Bad Route and Sweetgrass) were assigned a rating of "good". Consequently, there was not a large sample of "good" sites to employ in determining the average of mainline traffic percentage for this category. Due to the lack of variety in condition ratings in this category, it is difficult to draw a conclusion from this analysis.

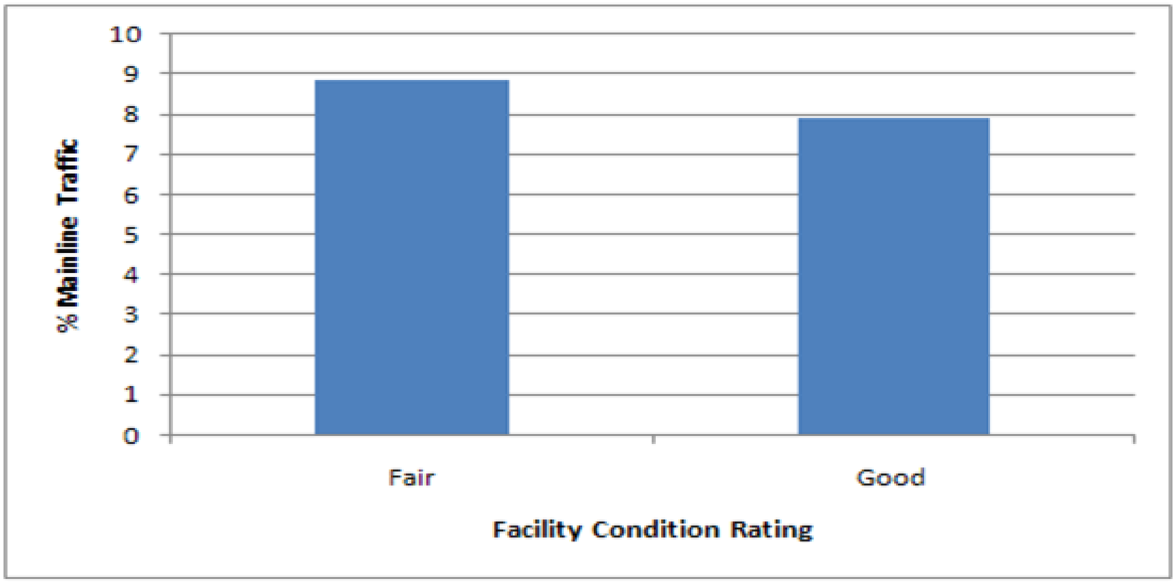


Figure 22: Low-Volume Interstate Rest Areas: Condition Rating vs. Rest Area Usage

Figure 23 presents the daily distribution of rest area usage. As expected, the highest usage was observed during the midday lunch period. However, a significant percentage of rest area usage was once again observed during the early morning hours, similar to the high-volume interstate category.

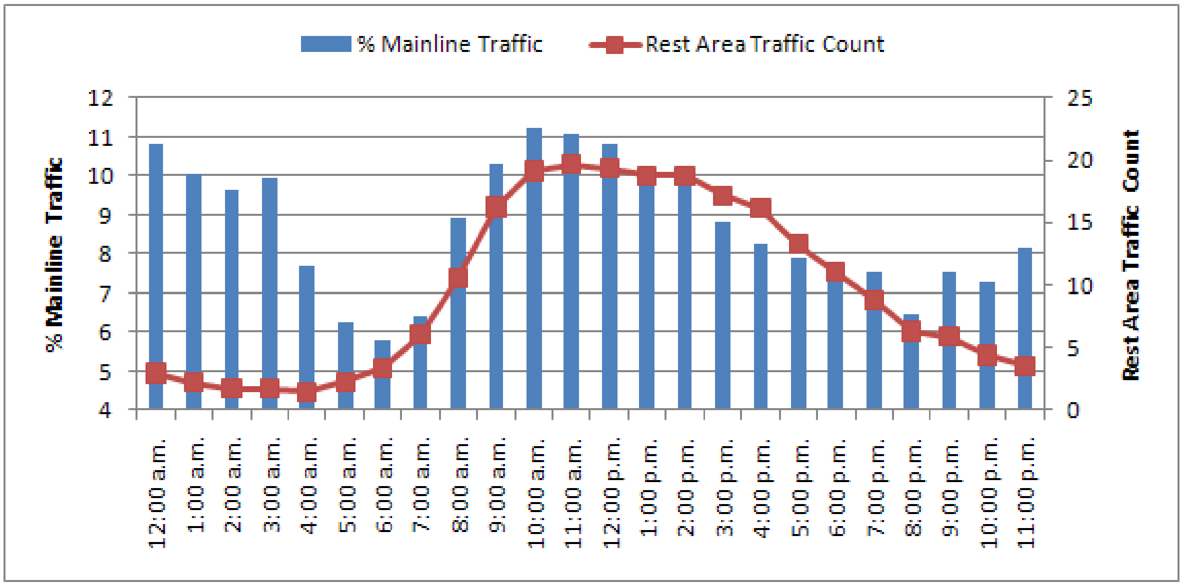


Figure 23: Low-Volume Interstate Rest Areas: Daily Distribution of Rest Area Usage

Figure 24 presents the weekly distribution of usage for the low-volume interstate category. No significant difference exists between days, although once again Wednesday was found to have the highest rest area usage. Friday and Saturday were anticipated to see the highest usage for tourist traffic, but once again, these two days appear to see similar usage compared to others. Also of note, Friday was found to have the lowest percent usage throughout the week.

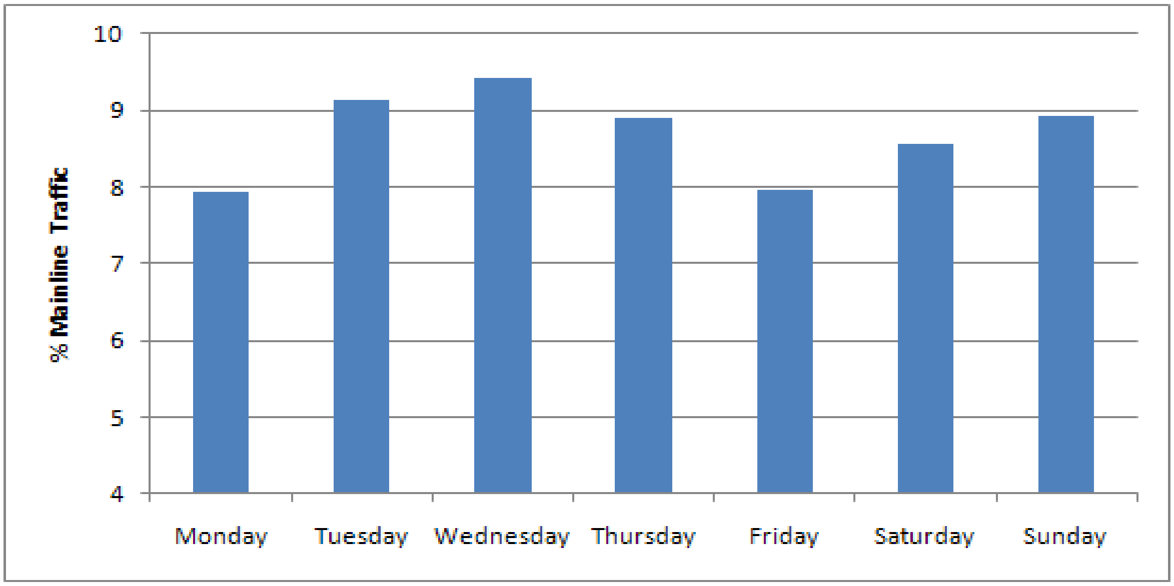


Figure 24: Low-Volume Interstate: Weekly Distribution of Rest Area Usage

The weekly average of percentage of rest area usage for the control station representing this category (Divide SB) is presented in Figure 25. Divide SB exhibited similar percent usage trends to that found at the Greycliff EB site (discussed in the previous section). Interestingly, the decrease in percent usage during the latter period of 2009 did not occur until mid-October, while at the Greycliff EB site this decrease occurred during mid-September. The reason for this difference is not known.

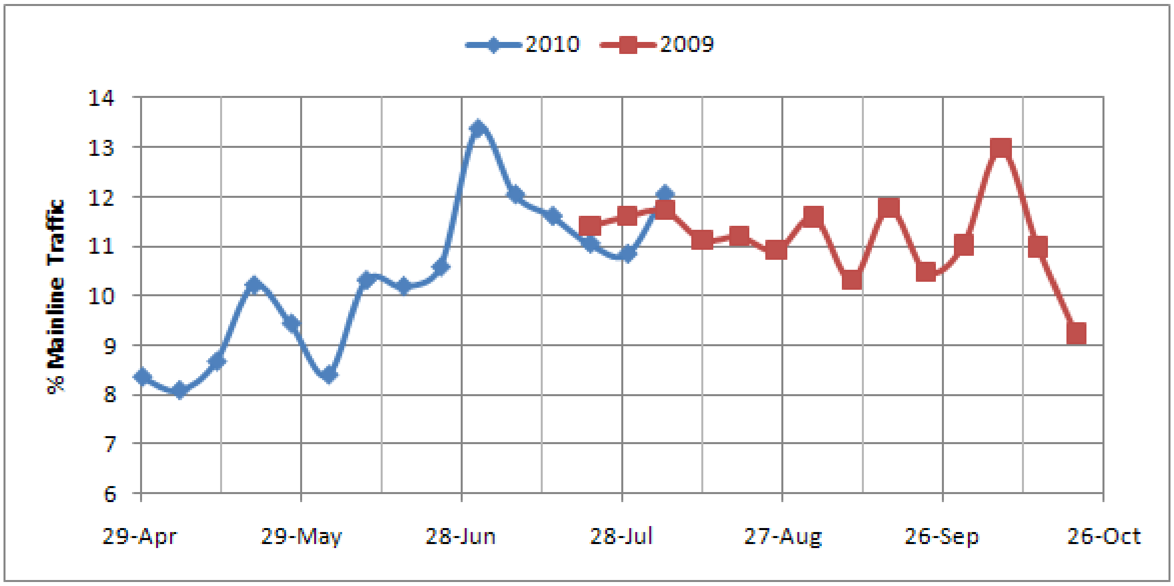


Figure 25: Low-Volume Interstate Rest Areas: Divide SB Seasonal Rest Area Usage

High-Volume Arterial

This category included all rest areas located on high volume arterials with a mainline AADT greater than 3,000 vehicles per day. This category consisted of four sites: Armington, Bridger, Clearwater Junction, and Troy, with Bridger serving as the control station. This category included the smallest number of study sites, and therefore, the least amount of field data collected. Table 21 presents the descriptive statistics for usage in the high volume arterial category. The average percentage of hourly mainline traffic entering the rest area was approximately 9.1. The median usage for this category was approximately 7.1 percent. The standard deviation was approximately 7.7 percent. As the standard deviation was greater than the mean, this suggested a high deviation amongst the data, consistent with the previous categories examined.

Table 21: High-Volume Arterial Rest Areas: Frequency of Use

Mean	9.14%
Median	7.14%
Mode	5.00%
Standard Deviation	7.71%
85th Percentile	17.37%
90th Percentile	21.18%
95th Percentile	25.00%
Range	0-35.84%

Figure 26 presents the frequency histogram of the occurrences of mainline traffic percentages entering the rest areas in this category. Note that many of the zero values observed occurred during night hours when no vehicles entered a rest area. Excluding the zero values, the distribution displayed multiple peaks with a somewhat positive skew, similar to that found for the previous categories. The maximum value was found to be just above 35 percent entering.

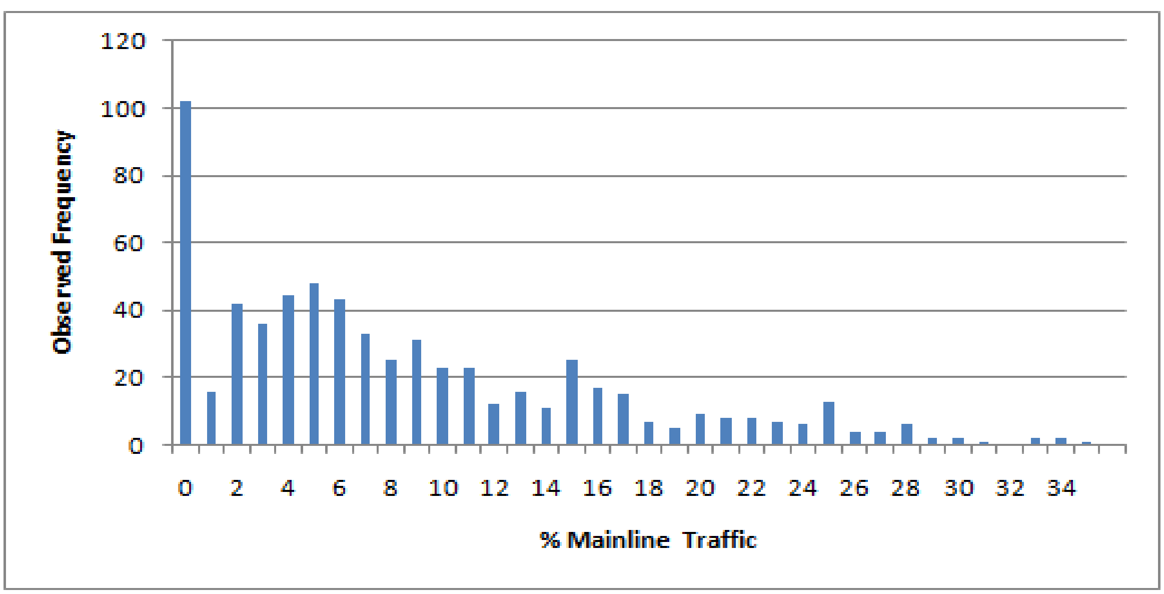


Figure 26: High-Volume Arterial Rest Areas: Frequency Histogram

Figure 27 presents the cumulative frequency curve for this category. The distribution appears to follow an S-shape. This distribution also shows the significant number of zero values, which was previously discussed. Note that for this group, zero values comprised over 20% of the total observations.

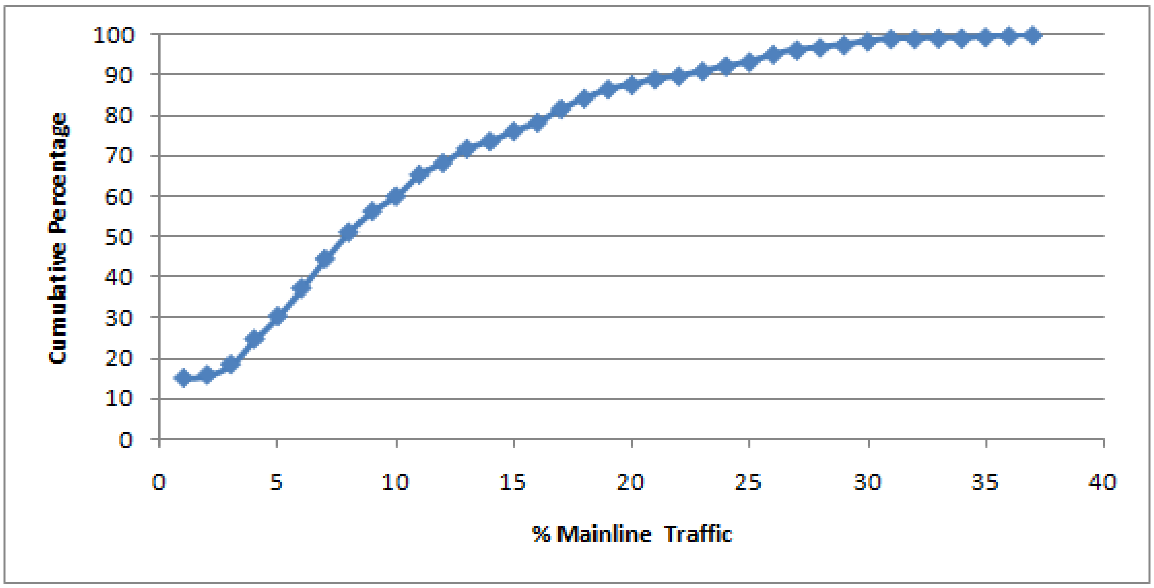


Figure 27: High-Volume Arterial Rest Areas: Cumulative Frequency Curve

Figure 28 presents the proportion of trucks entering a rest area versus the percentage of mainline traffic at a site. Note that an inverse relationship to the usage exists, suggesting that truck usage may increase as mainline traffic levels decrease. It should be noted that the truck proportion in this category only varied from between 8.5 percent to 13.9 percent, making it difficult to draw a definitive conclusion from this observation.

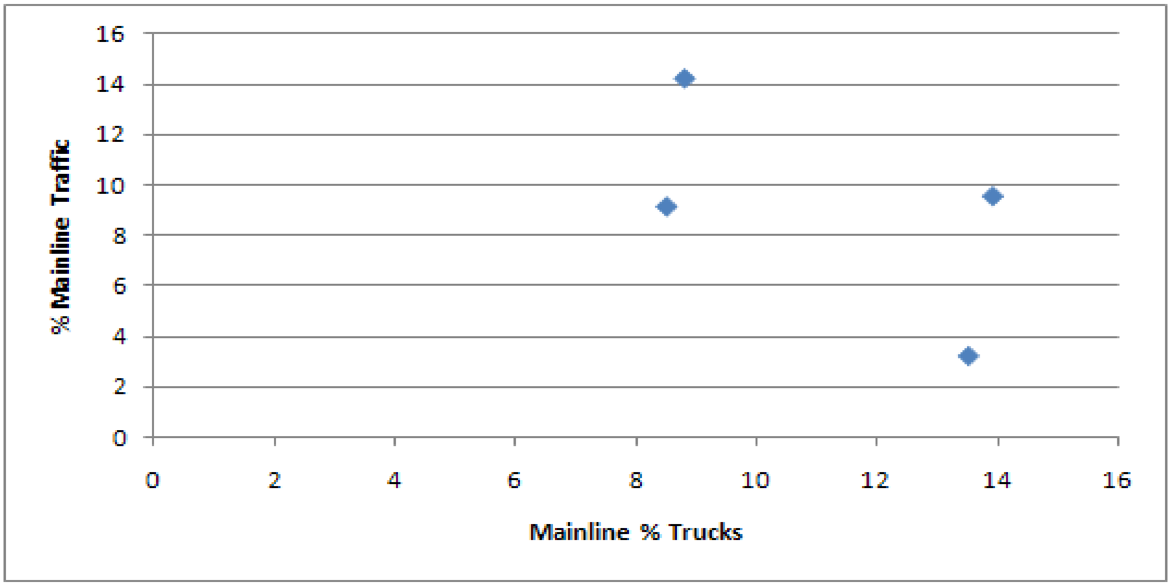


Figure 28: High-Volume Arterial Rest Area Usage vs. Truck Proportion

Figure 29 presents the relationship between different distance variables and the rest area usage. The distance variables all exhibited weak relationships. No definitive patterns are readily apparent, similar to the previous analyses. The upstream and downstream rest area distance variables showed a logical positive increase, however the upstream and downstream city variables showed a somewhat illogical negative decrease. It is difficult to draw any definitive conclusions for this category based on the limited sample size of study sites.

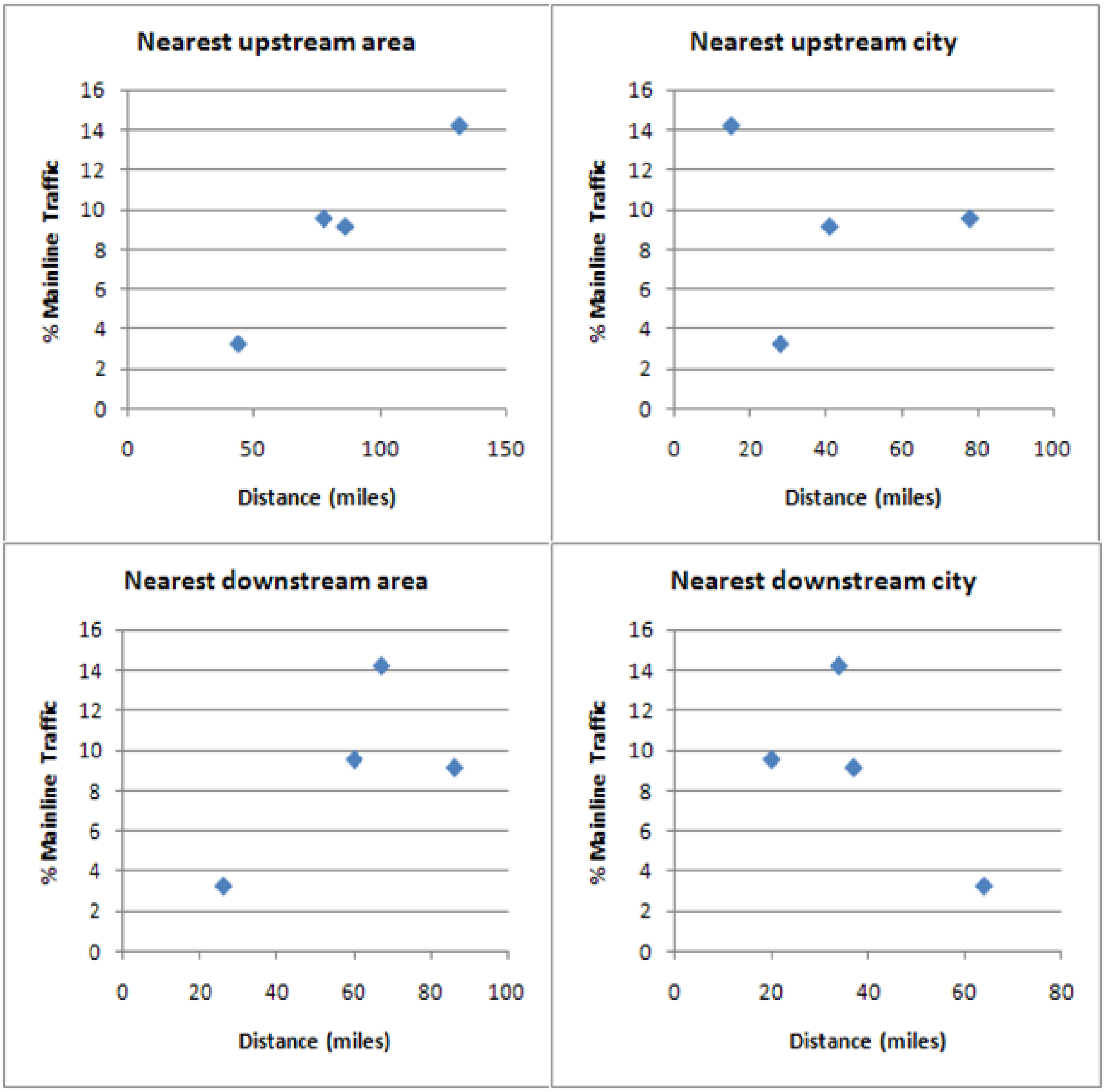


Figure 29: Plots of Distance Variables vs. Rest Area Usage

The condition of the rest area facility versus percent usage showed an unexpected result, as illustrated by Figure 30. Sites in fair condition saw higher usage rates, which one would not necessarily expect. Note that none of the rest areas in this category were given a condition rating of "poor".

Figure 30: High-Volume Arterial Rest Area Usage vs. Facility Condition

Figure 31 indicated that presence of a weigh station in operation adjacent to a rest area facility resulted in an increase in rest area usage. This finding is likely the result of the concept of induced demand. Induced demand created the phenomenon in which a truck driver was more likely to stop at a rest area with an open weigh station facility adjacent to it compared to a typical rest area. As the truck driver was required to stop at the weigh station, they also used this opportunity to visit the rest area as well.

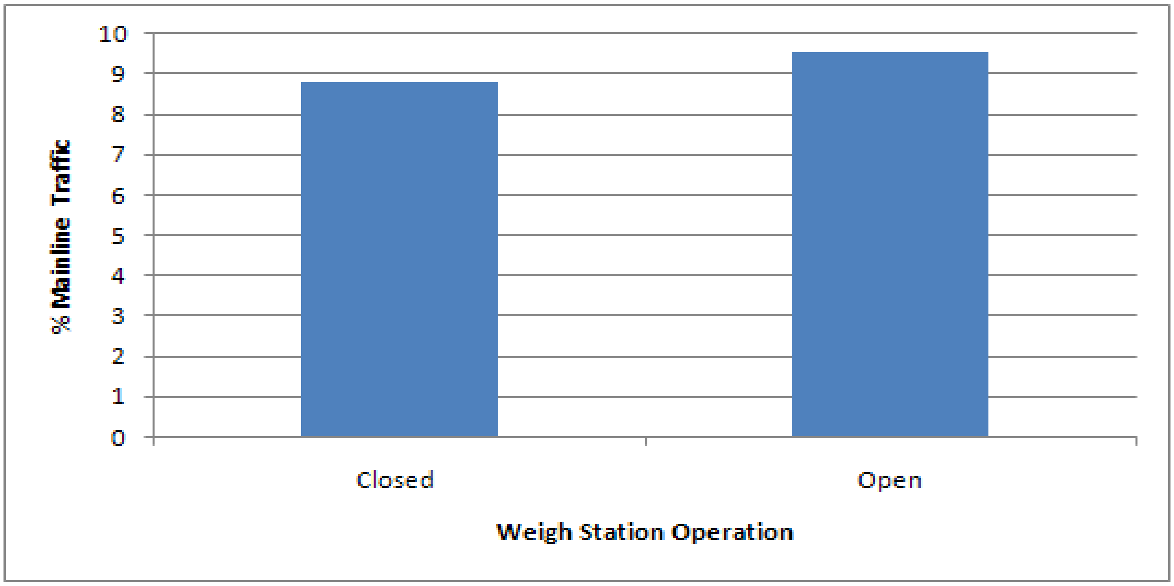


Figure 31: High-Volume Arterial: Weigh Station Operation vs. Rest Area Usage

The daily distribution of rest area usage is presented in Figure 32. The midday lunch hours showed the highest percent usage as well as the highest counts, consistent with expectations and what had been observed in other categories. The decrease in percent usage observed during the early morning hours was greater for rest areas in this category relative to other rest area categories. Given the small sample size of this category, no definitive conclusions should be drawn from this trend.

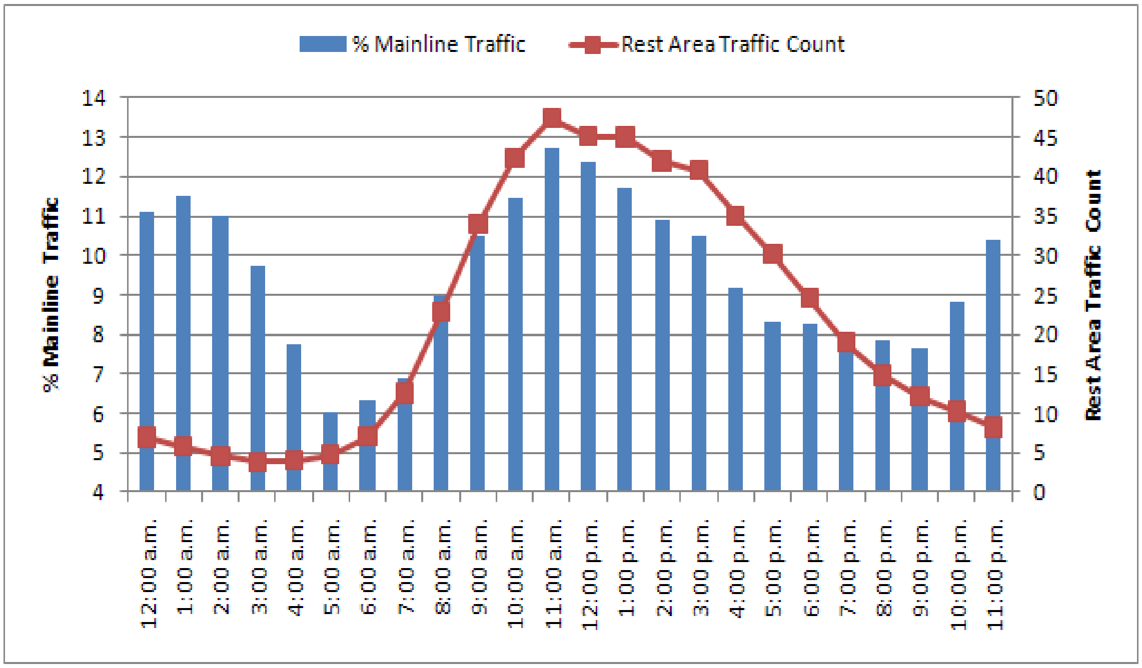


Figure 32: High-Volume Arterial Rest Areas: Daily Distribution of Usage

Figure 33 presents the weekly distribution of usage for the category. As expected, later days of the week experienced a higher usage. The lowest usage occurred on Monday (5.2%), with the highest usage on Saturday (6.9%). Sunday provided a lower usage relative to all other days except Monday, which does not concur with hypotheses that usage would be high the entire weekend.

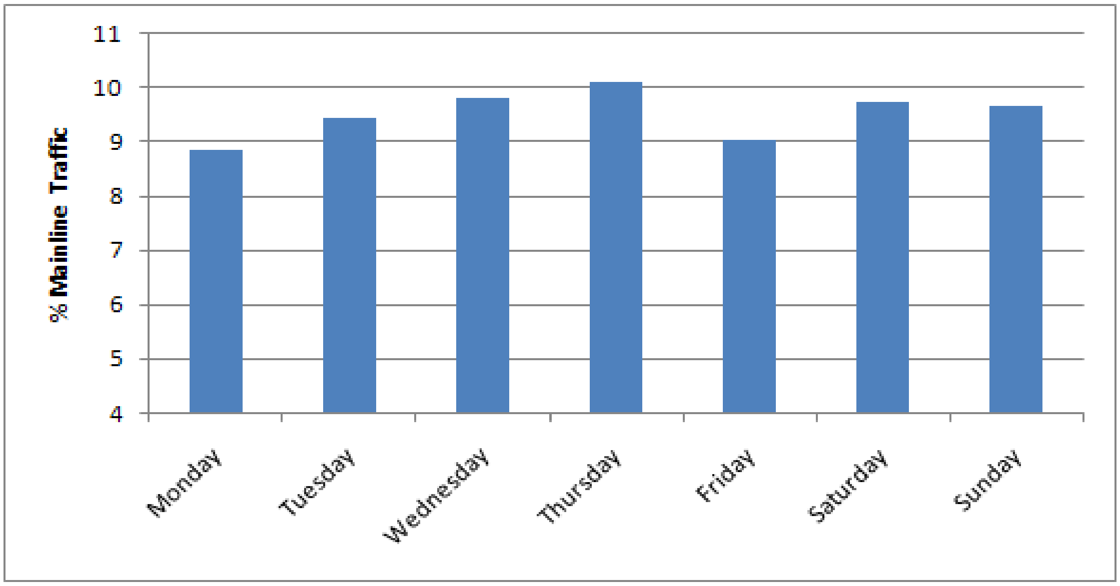


Figure 33: High-Volume Arterial Rest Areas: Weekly Distribution of Usage

Due to the lack of available mainline traffic data from an ATR in the area of the control station for this category (Bridger), two separate plots containing weekly average rest area traffic counts (one for the year 2009 and one for 2010) were developed. Figure 34 and Figure 35 present information illustrating the seasonal variation of rest area usage at the Bridger control station site.

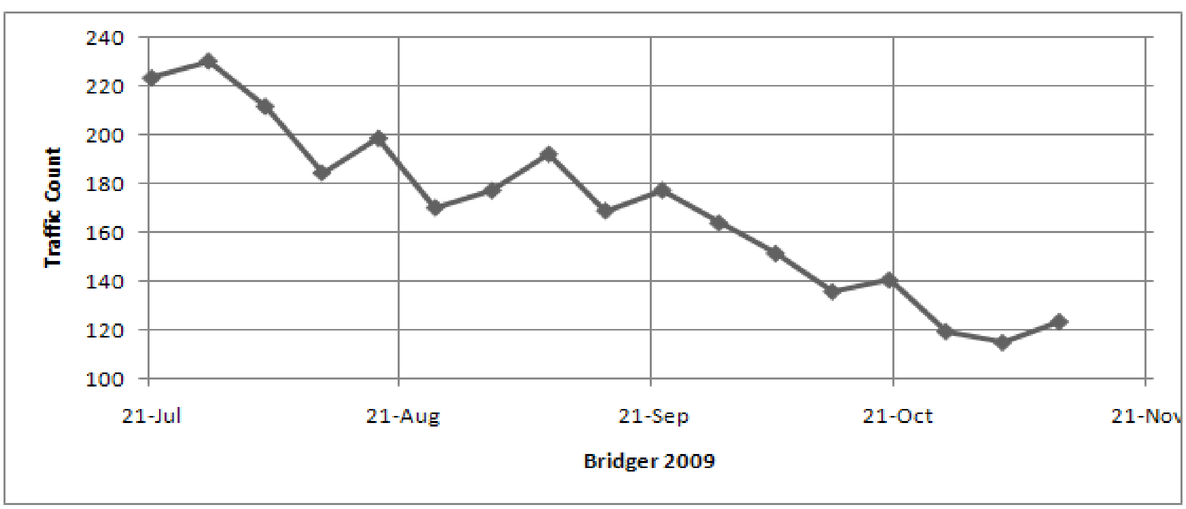


Figure 34: Bridger Seasonal Rest Area Usage (2009)

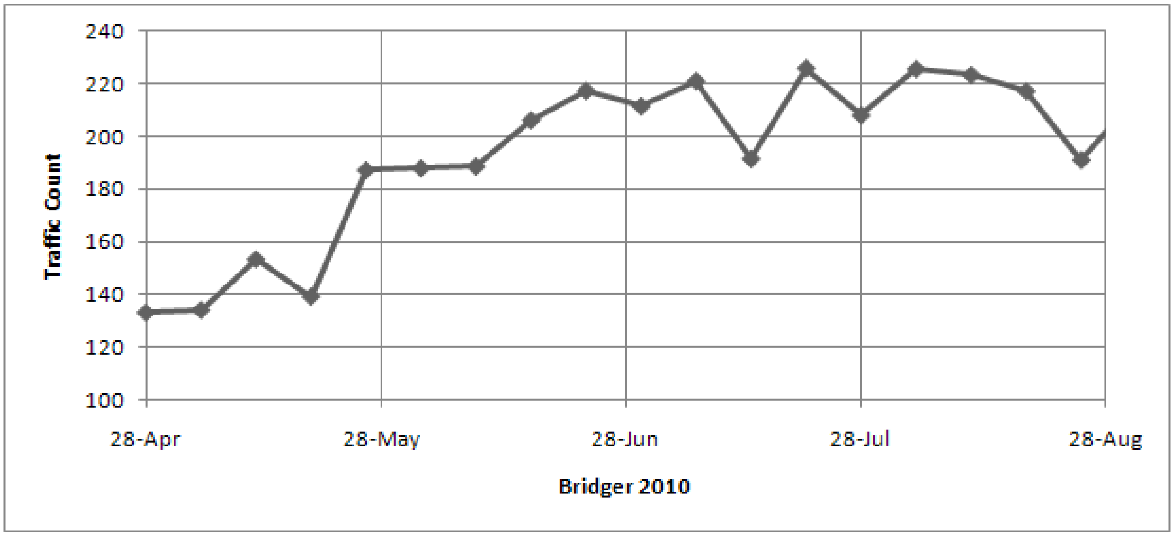


Figure 35: Bridger Seasonal Rest Area Usage (2010)

As shown in Figure 34, the traffic counts at the Bridger rest area decreased approximately linearly between late July and the middle of November in 2009, suggesting the peak usage for this site occurred late July. The 2010 traffic counts at the site showed a parabolic trend, as illustrated in Figure 35, with the peak count occurring in mid-August. This trend slightly differs from what was observed in 2009, but without mainline traffic data available, it is not clear what the cause for this trend may have been.

During the course of the analyses, it was found that the Bridger site exhibited a lower average percentage of usage relative to the other sites in this category (6.6 percent versus 15.2, 18.8, and 19.1 percent for other sites). Therefore, a secondary analysis was performed which excluded data from the Bridger site. These results are presented in the next section.

High-Volume Arterial (Excluding Bridger Site)

As previously discussed, the challenge associated with the high-volume arterial category was that the sample size of traffic data from the Bridger site was drastically different than all other sites in the group. Consequently, it was of interest to reexamine data for the category after data from the Bridger group had been removed. This section presents the results of that analysis, with only data from Armington, Clearwater Junction, and Troy examined.

Table 22 presents the descriptive statistics for this category both including and excluding the Bridger site. Note that nearly all values provided in the table notably increased when the Bridger site was excluded, which was expected. The mean for this category rose to approximately 11 percent, with the 85th, 90th, and 95th percentiles ranging from 20 percent to 26 percent. The standard deviation also increased slightly, suggesting more variance within the data.

Table 22: High-Volume Arterial Rest Area Usage, Excluding Bridger site

Statistic	**High-Volume Arterial w/o Bridger**	**High-Volume Arterial**
Mean	10.96%	9.14%
Median	9.47%	7.14%
Mode	7.00%	5.00%
Standard Deviation	8.00%	7.71%
85th percentile	20.00%	17.37%
90th percentile	23.13%	21.18%
95th percentile	26.08%	25.00%
Range	0-35.84%	0-35.84%

The frequency histogram for the percent rest area usage is presented in Figure 36. This histogram does not resemble the bell shape associated with a normal distribution, as was found for the previous analysis including the Bridger site. Rather, it appears that the frequency of percent mainline traffic entering the rest area is highly variable at the sites included in this analysis.

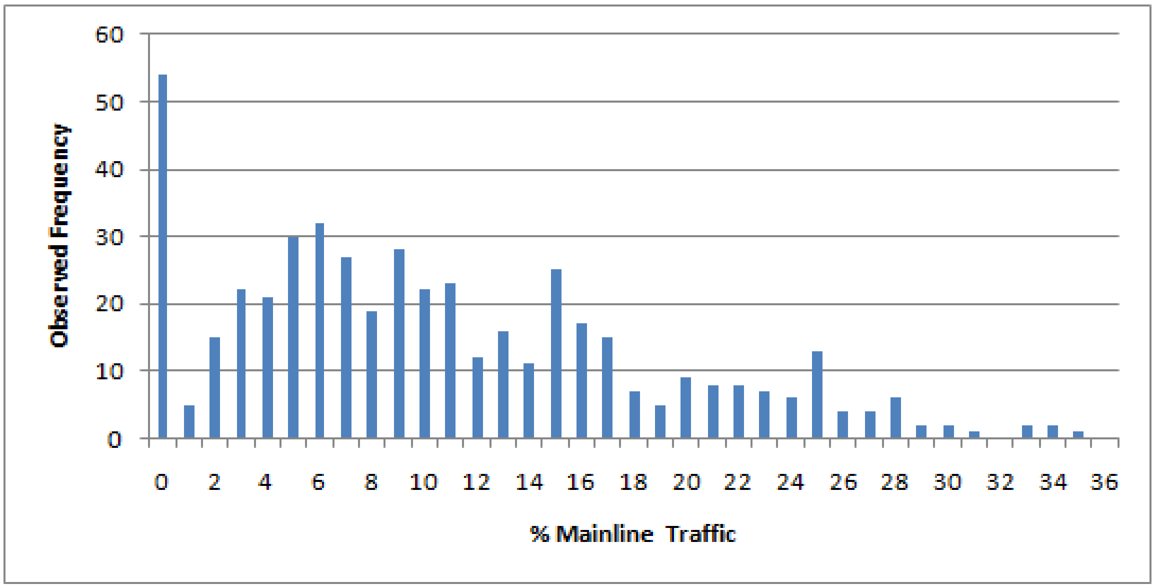


Figure 36: High-Volume Arterial Rest Areas (Excluding Bridger): Frequency Histogram

The cumulative frequency curve in Figure 37 shows that the distribution slightly differed without the Bridger site, as this distribution does not entirely resemble the S-shape observed previously.

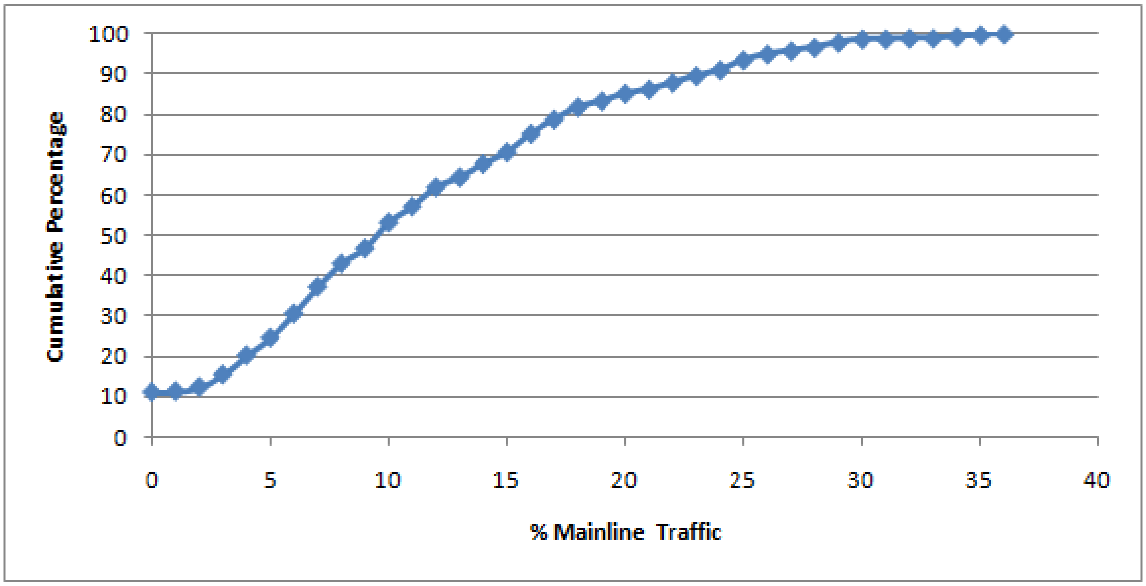


Figure 37: High-Volume Arterial Rest Areas (Excluding Bridger): Cumulative Frequency Curve

Figure 38 presents the relationship between the truck proportion entering the rest areas and the proportion of mainline traffic entering. No discernable relationship was determined from this graph, primarily because it includes only three data points. The percentage of trucks entering and the percentage of rest area usage showed little variation for this data set (usage varied from 11% to 15% and the truck proportion varies from 8.5% to 13.9%).

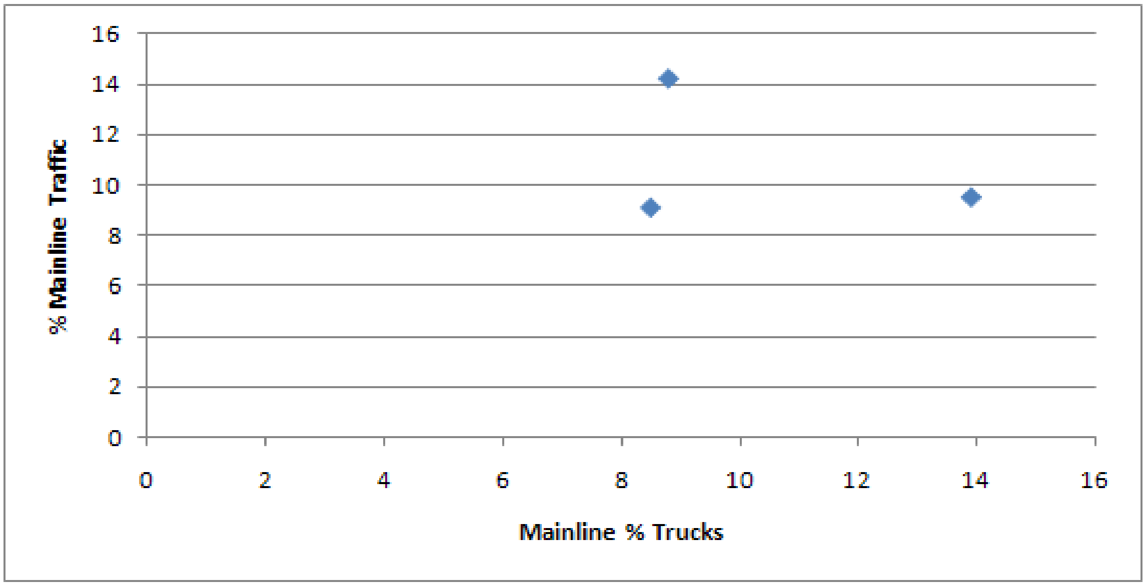


Figure 38: High-Volume Arterial (Excluding Bridger):
Truck Proportion vs. Rest Area Usage

Figure 39 presents the plots of the distance variables against the rest area usage. The upstream city displays an illogical trend, which was not observed when the Bridger site was included in this category. Similarly, the trend for the downstream city distance was also illogical for this data set. However, no distinct pattern could be discerned from these graphs due to the small number of sites employed.

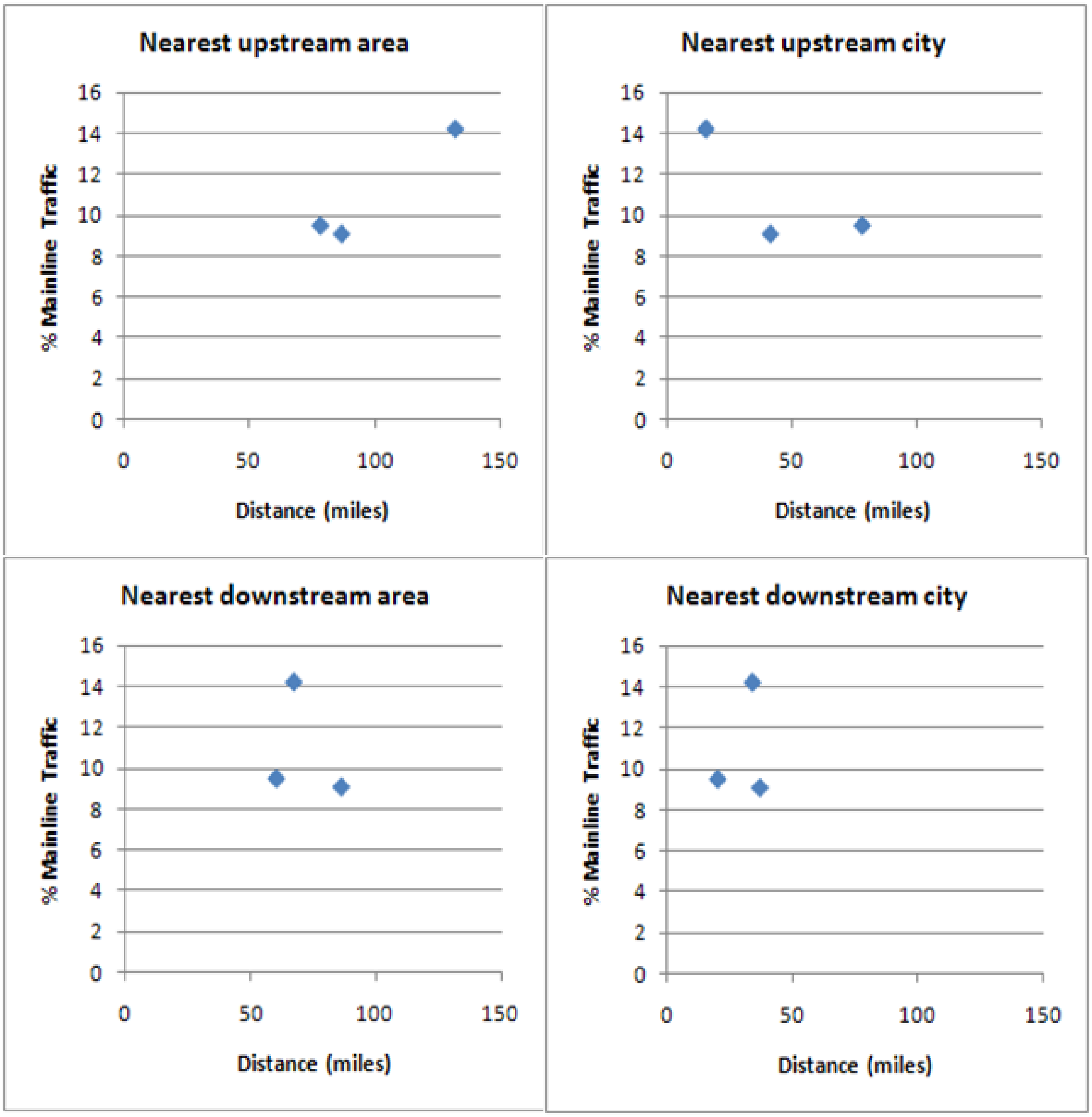


Figure 39: Plots of Distance Variables vs. Rest Area Usage

Figure 40 presents a comparison of usage with site condition rating. The relationship between condition and usage did not entirely follow what was expected, in that the lower condition rating sites exhibited higher usage. This result matched that observed when the Bridger site was included.

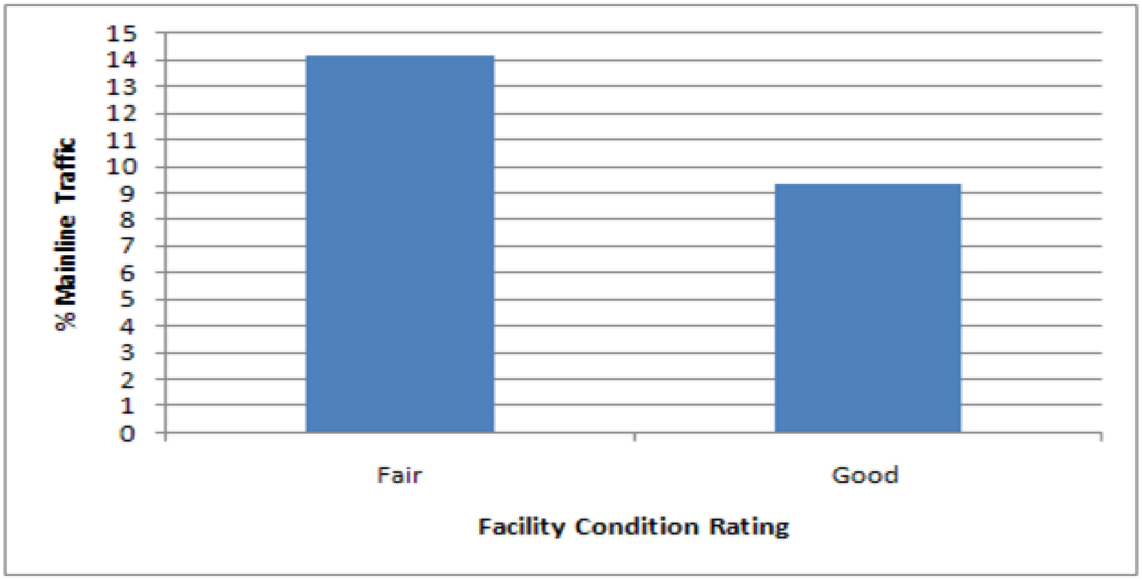


Figure 40: High-Volume Arterial (Excluding Bridger):
Condition Rating vs. Rest Area Usage

Figure 41 presents a comparison of the rest area usage by the hour of the day. As expected, the highest usage occurred during the noon lunch period, similar to the previous analysis. The general shape of the graph was also similar, with the major difference being the averages of entering mainline traffic being higher. Also, an increase in the percent rest area usage during the 5 to 6 a.m. hour was observed, which differed from previous observations.

Figure 42 presents the weekly distribution of rest area usage. Fridays and Saturdays displayed the highest usage, which corresponds to the days in which most tourist and recreational travel was likely to occur.

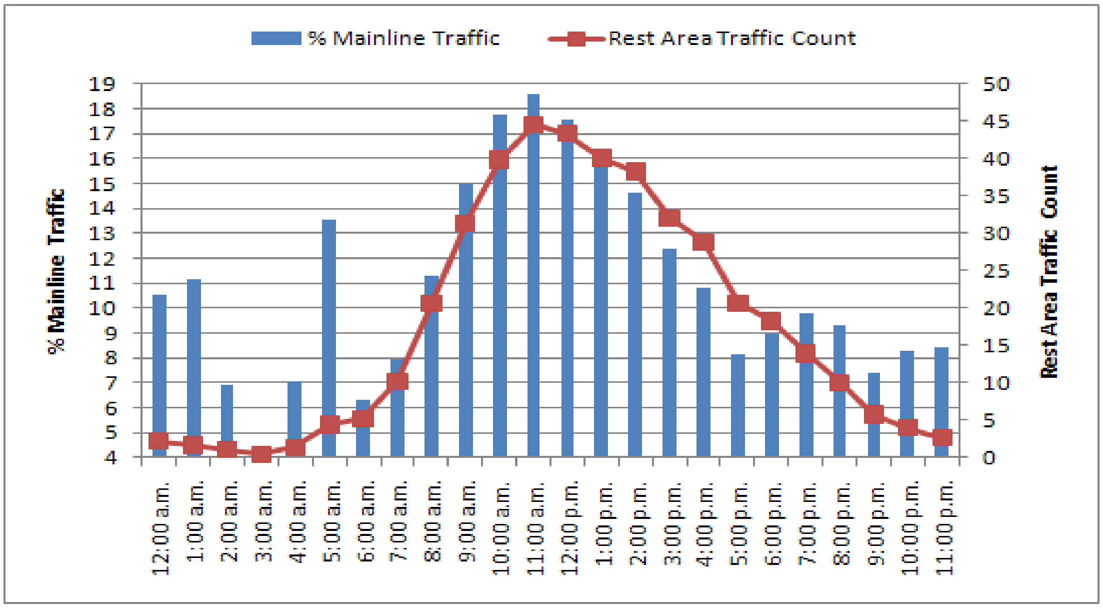


Figure 41: High-Volume Arterial (Excluding Bridger):
Daily Distribution of Rest Area Usage

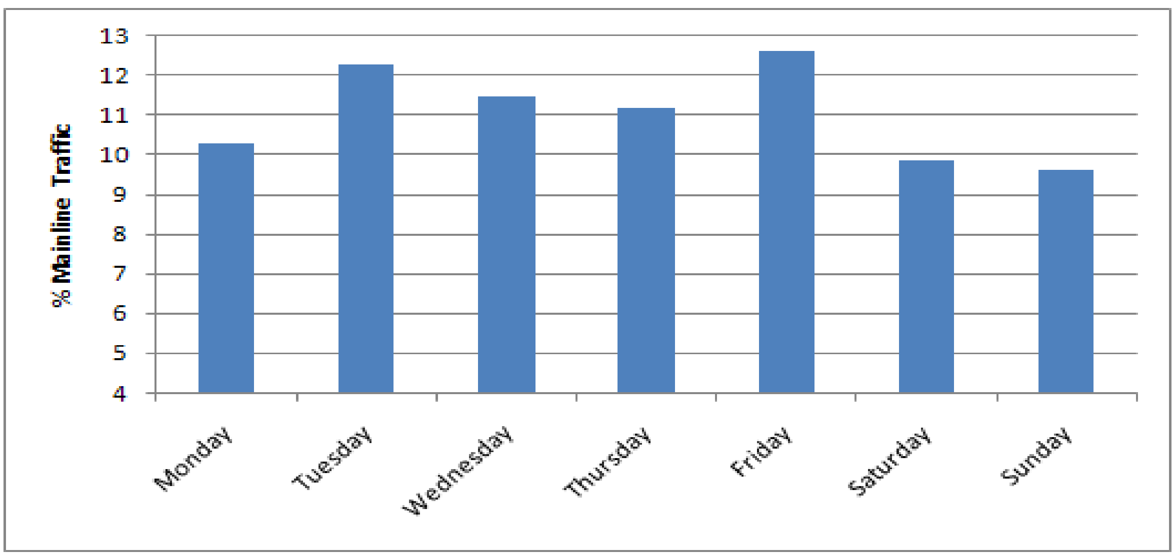


Figure 42: High-Volume Arterial (Excluding Bridger) Weekly Distribution of Rest Area Usage

<u>Low-Volume Arterial</u>

This category included all rest areas on non-interstate highways with an AADT less than 3000 vehicles per day. This included ten sites: Broadus, Culbertson, Emigrant, Flowing Wells, Lost Trail Pass, Mosby, Raynolds Pass, Roberts, Vandalia, and Vista Point.

Table 23 presents the descriptive statistics for this category. The average percentage of mainline traffic entering the rest area representing usage was approximately 13.4 percent. The standard deviation for this category was 18.05 percent, suggesting an extremely high variance within the data. The 85th, 90th, and 95th percentiles were approximately 25 percent, 33 percent, and 43 percent, respectively.

Table 23: Low-Volume Arterial Rest Areas: Frequency of Use

Mean	13.39%
Median	7.73%
Mode (non-zero)	7.00%
Standard Deviation	18.05%
Range	0-100%
85th percentile	25.07%
90th percentile	33.33%
95th percentile	43.14%

Figure 43 and Figure 44 present the frequency histogram and cumulative frequency curve for rest area usage on low volume arterials. Figure 43 indicates that the distribution approximately follows a positively skewed bell-shaped distribution, similar to that of other categories. The greatest number of zero values of rest area usage was observed in this category due to the low-volume nature of several sites in the category. The cumulative frequency distribution for this category presented in Figure 44 resembles the S-shape associated with a normal distribution, with the majority of usage observations falling below 50 percent.

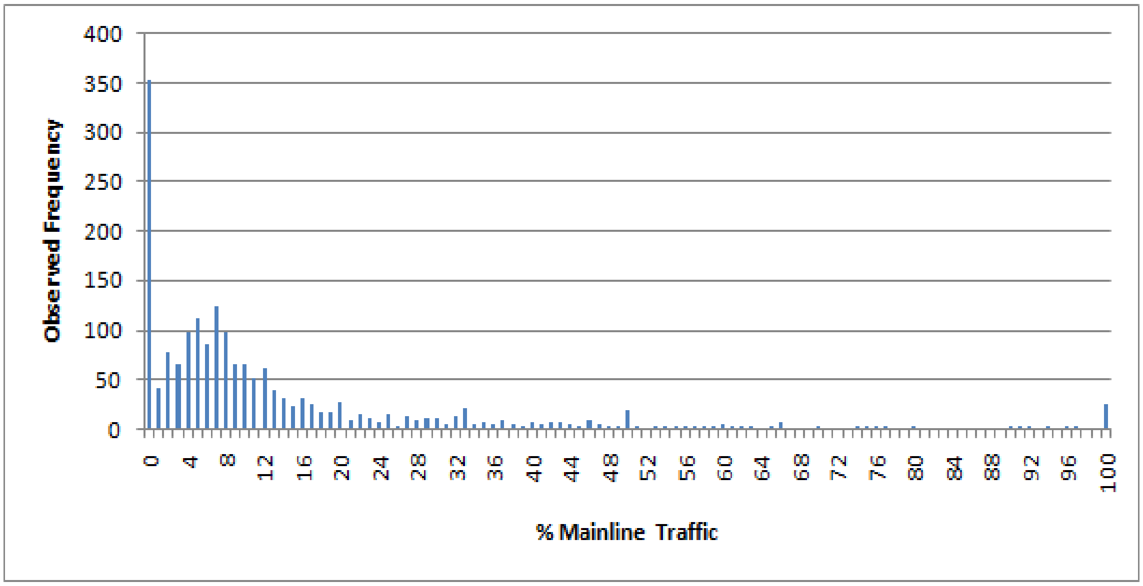


Figure 43: Low-Volume Arterial Rest Areas: Frequency Histogram

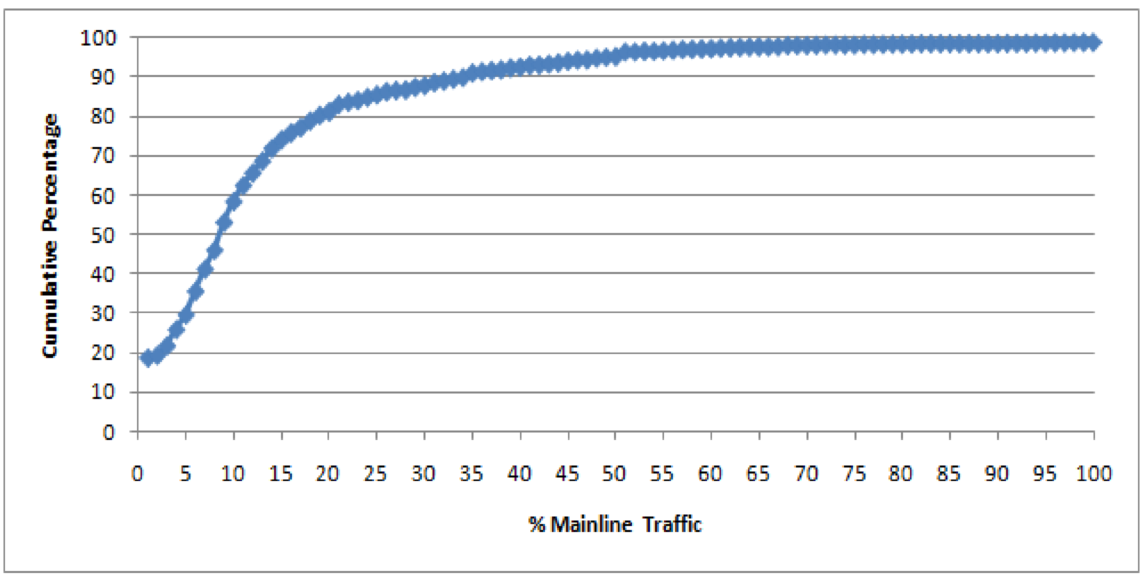


Figure 44: Low-Volume Arterial Rest Areas: Cumulative Frequency Curve

The plot of percent trucks compared to percent rest area usage for this category presented in Figure 45 indicates a potentially linear relationship between the two variables. The exceptions to this trend are the three study sites on the lower right of the plot. This would seem to confirm the expectation that as mainline traffic usage at a rest area increases, so too does the proportion of trucks entering the rest area.

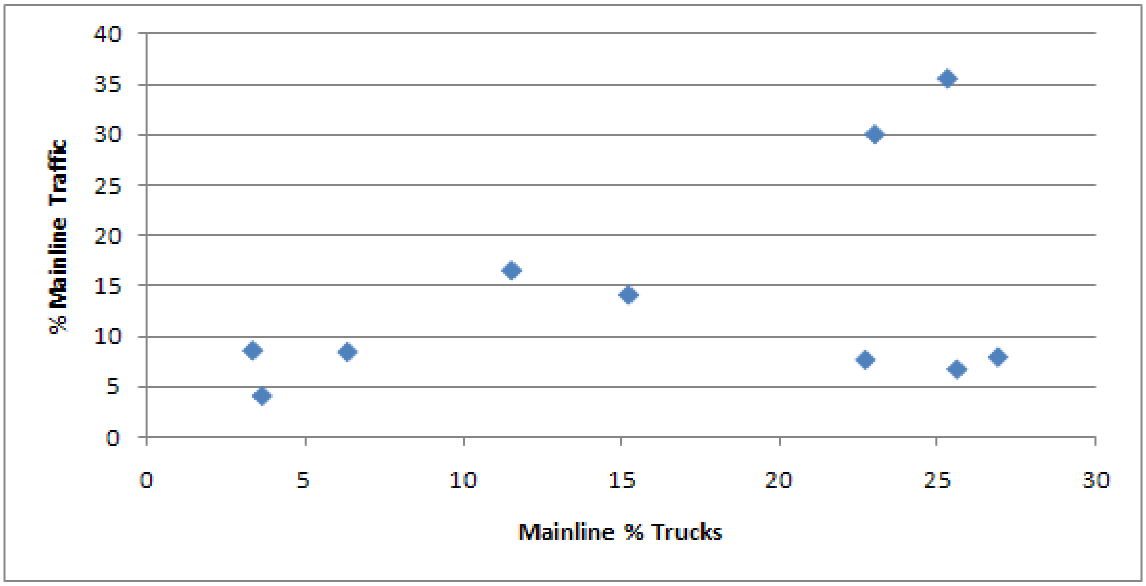


Figure 45: Low-Volume Arterial Rest Areas: Truck Proportion vs. Rest Area Usage

In examining the plots presented in Figure 46, no apparent relationship existed between distance variables and the rest area usage. None of the distance variables exhibited clear relationships, underscoring the randomness of rest area usage at low-volume arterial sites.

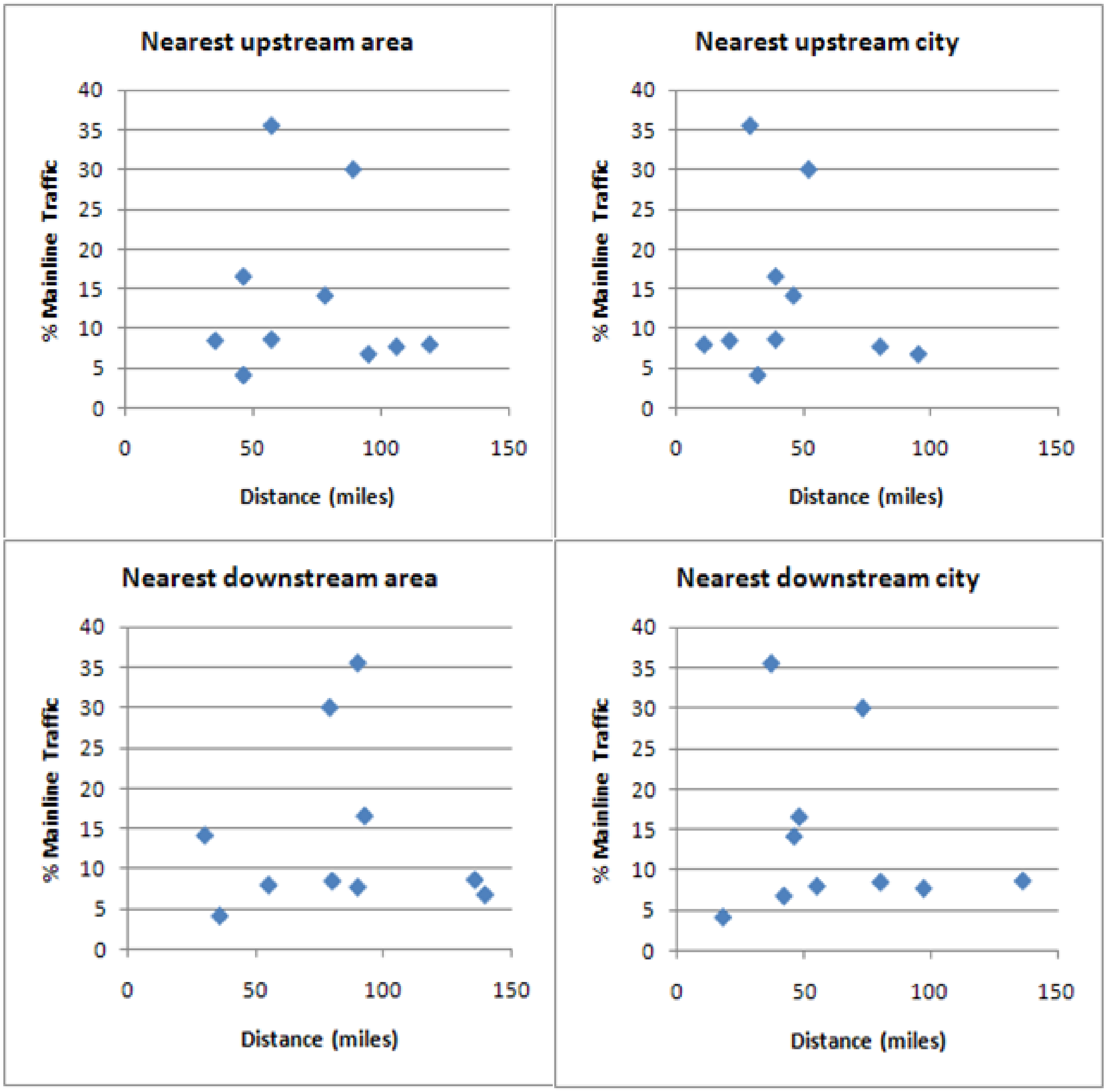


Figure 46: Plots of Distance Variables vs. Rest Area Usage

Figure 47 illustrates the expected relationship between rest area condition and usage. In other words, rest areas with higher overall conditions have higher rates of usage. In this category, five rest areas were given a "good" overall condition rating, three received a "fair" rating, and two were "poor". The percentage of rest area usage increases dramatically from "fair" to "good", suggesting that the increase of percent rest area usage with an increase in condition rating may not be linear for low volume arterials.

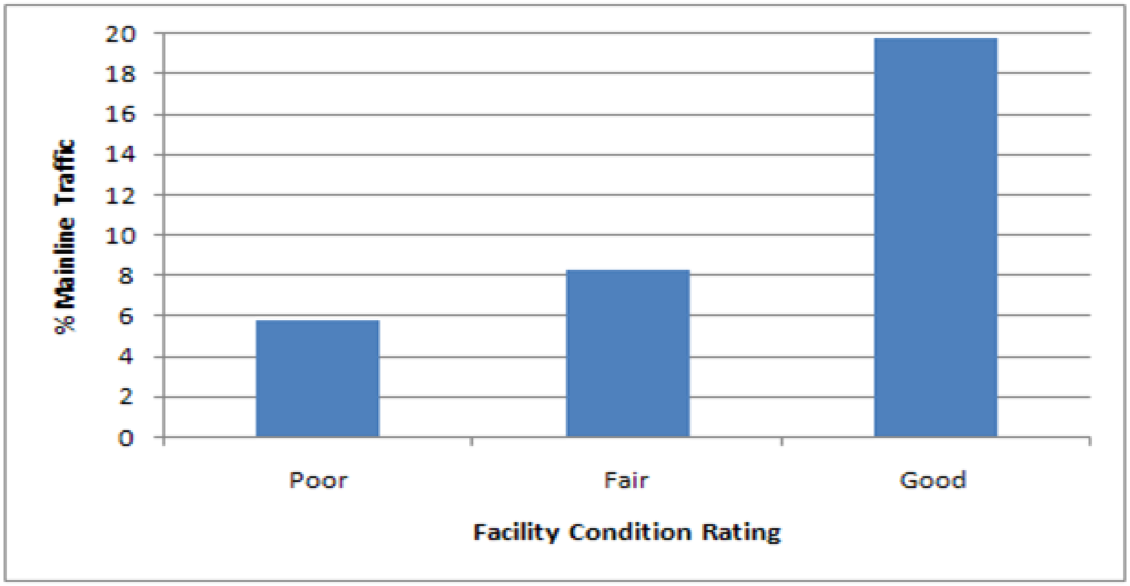


Figure 47: Low-Volume Arterial Rest Areas: Condition Rating vs. Rest Area Usage

As illustrated in Figure 48, rest area usage appeared to increase significantly with the presence of a weigh station in operation. However, no definitive conclusion can be drawn from this observation, as only one rest area in this category (Culbertson) had an adjacent weigh station.

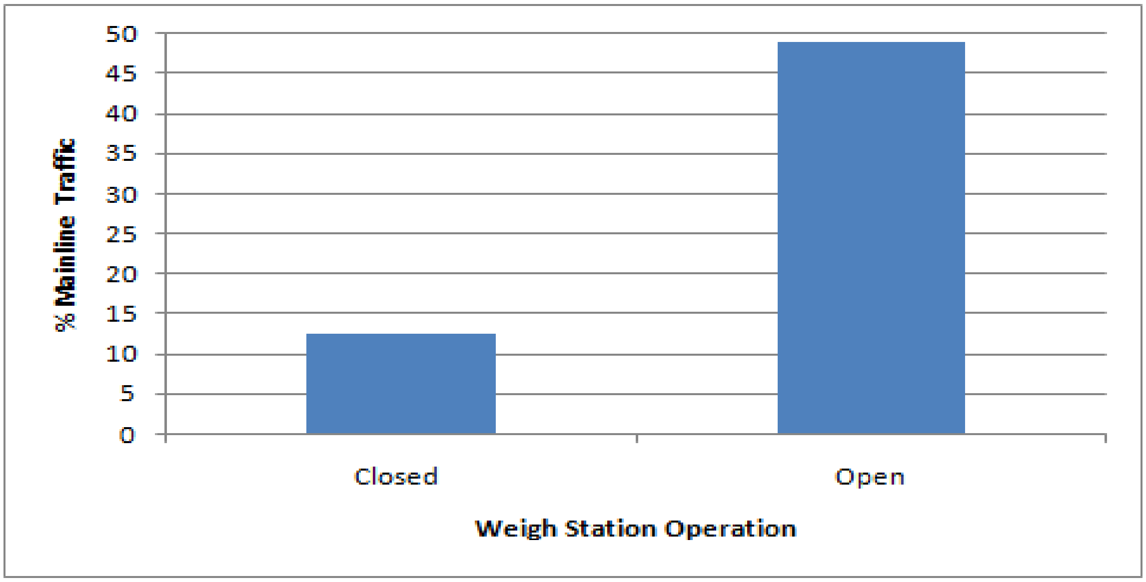


Figure 48: Low-Volume Arterial Rest Areas: Weigh Station Operation vs. Rest Area Usage

Figure 49 indicates that the presence of a visitor information center results in a decrease of rest area usage, which is contrary to expectations. Similar to the weigh station case, a definitive conclusion cannot be drawn from this observation, because only one rest area in this category (Broadus) had a visitor information center.

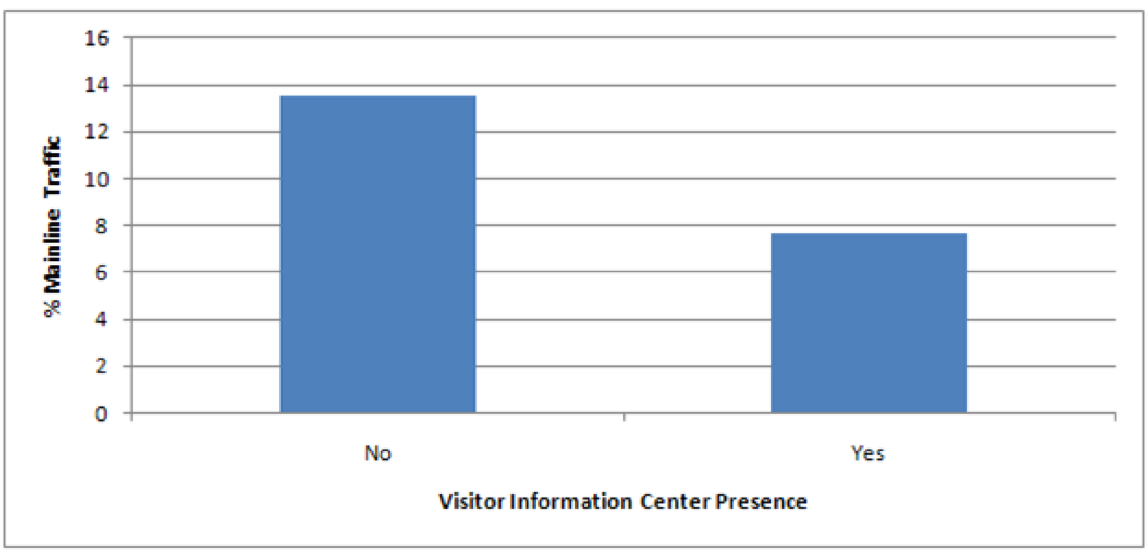


Figure 49: Low-Volume Arterial Rest Areas: Presence of Visitor Information Center vs. Rest Area Usage

The daily variation presented in Figure 50 suggested that the midday lunch period saw the highest percentage of rest area usage, similar to the other categories examined. The peak usage occurred between the hours of 10 a.m. and 3 p.m. However, the late night and early morning hours also saw a high percentage of use. This can be explained by the very low mainline traffic counts observed at the sites during these hours.

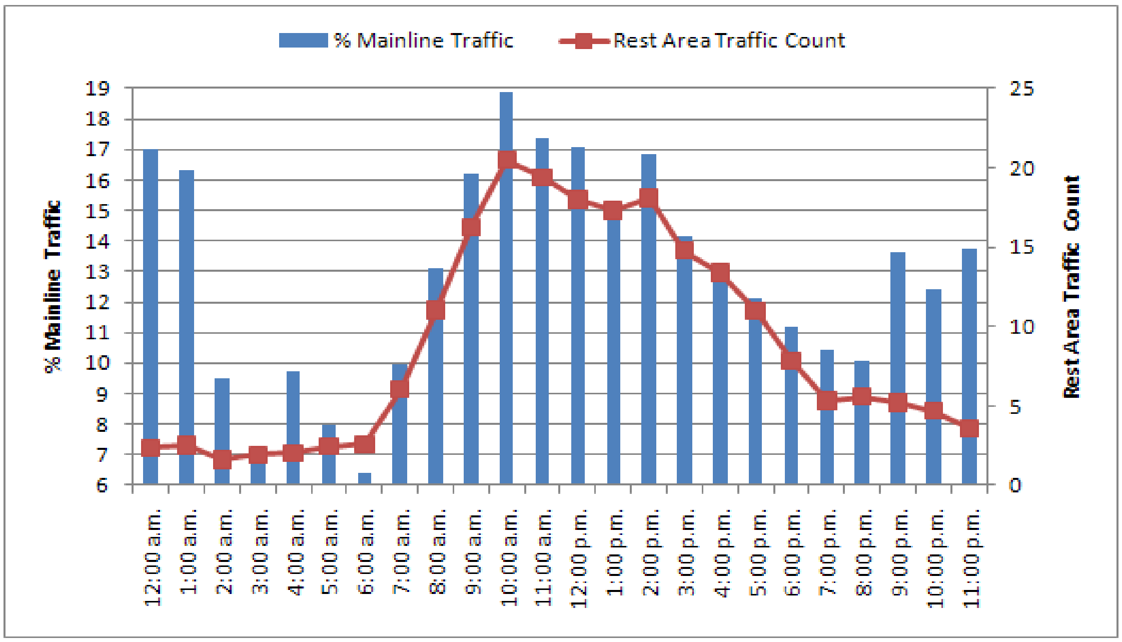


Figure 50: Low-Volume Arterial Rest Areas: Daily Variation of Rest Area Usage

The weekly variation presented in Figure 51 suggested that the rest areas in this category are used more on weekends compared to other days of the week, which was expected. However, the overall increase in usage does not appear to be significant.

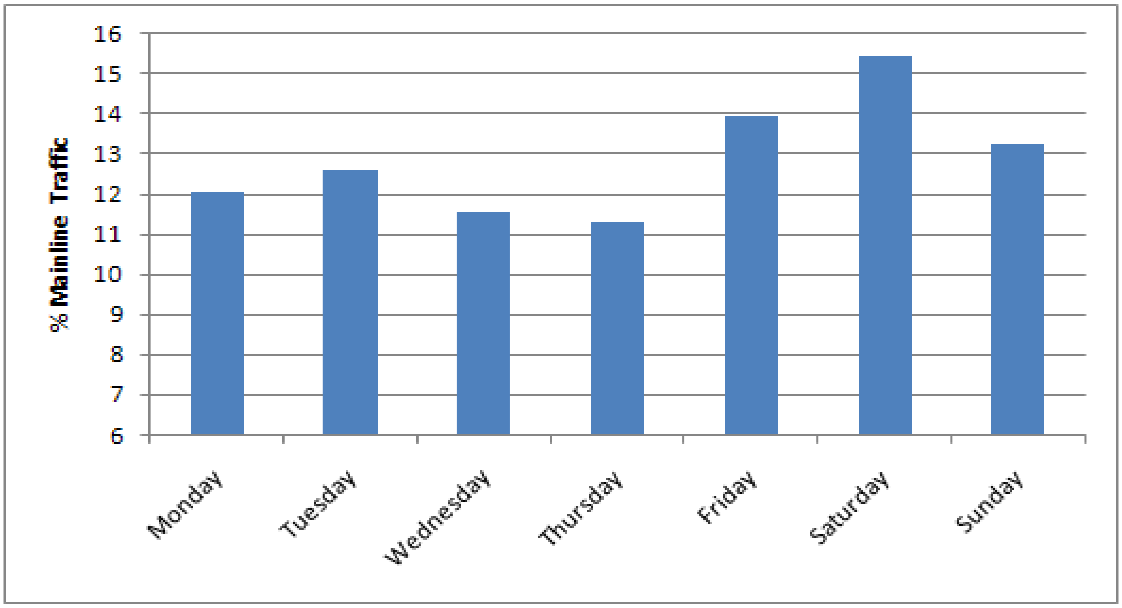


Figure 51: Low-Volume Arterial Rest Areas: Weekly Distribution of Usage

Figure 52 presents the seasonal variation of rest area usage at the low-volume arterial control station (Emigrant). This site exhibited a parabolic trend similar to other sites. The exception was the significant peak which occurred during late-August/early-September 2009. The reason for this peak is not entirely clear, although it may be the result of a trend in increased tourist traffic in the later summer by retirees. The Emigrant site is located on US 89, a route which sees significant traffic traveling to the Gardiner entrance of Yellowstone National Park. It is also possible that these high percent usage values were the result of estimations required because of a counter malfunction during this time period. Counts from the missing counter data were estimated using the counts from the other counter, potentially resulting in the higher observations. Note that this plot also shows that the percentage of rest area usage was greater in 2009 relative to 2010. This trend was not observed at the other control station sites in other categories.

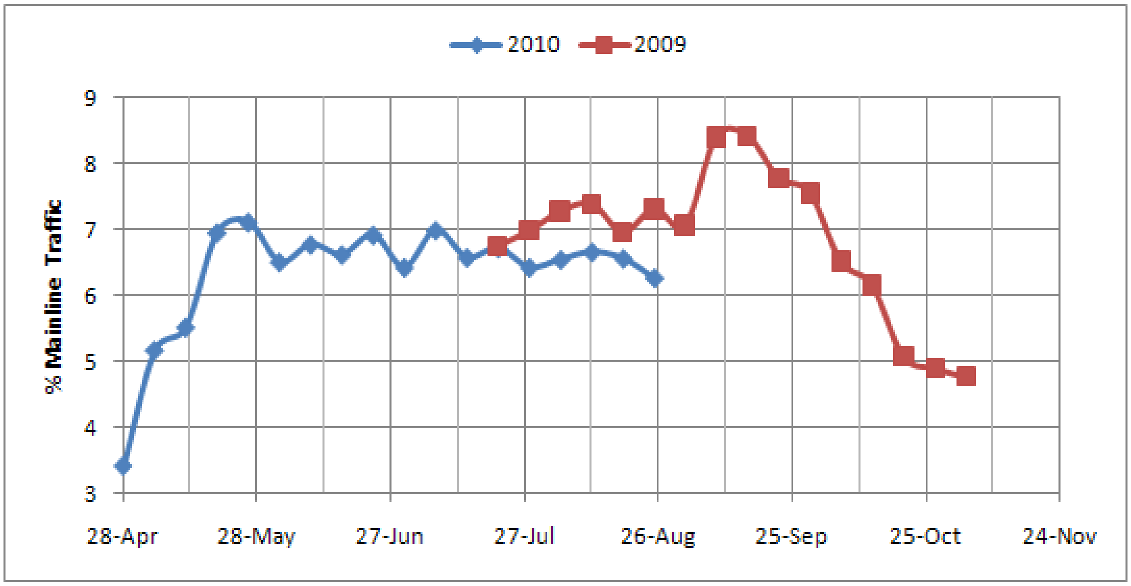


Figure 52: Low-Volume Arterial Rest Areas: Emigrant Seasonal Rest Area Usage

Statistical Analysis

This section discusses the various statistical analyses that were performed on the data by category. This includes correlation analysis as well as the modeling efforts. At the highest level, the data was broken down by rest area category (high-volume interstate, low-volume arterial, etc.). The results of the analysis performed on the various categories of data are presented in the following sections.

Correlation Analysis

In statistics, the correlation coefficient is a measure of the correlation (linear dependence) between any two variables X and Y, and takes a value between +1 and −1 inclusive. It is widely used as a measure of the strength of linear dependence between two variables. In this study, correlation coefficients were determined to further examine the relationship between different study variables and the rest area usage. Discussion of the results of these analyses is presented in the following sections for the different rest area categories, including trends that were identified which either supported or violated research hypotheses and the strengths of the various relationships.

High-Volume Interstate: Table 24 presents the correlation coefficients for rest area usage, as expressed in the relationship between percent entering and different distance, truck proportion and condition variables for the high-volume interstate category. The nearest city distance variables showed weak correlations with the rest area usage relative to the nearest rest area distance variables. However, the nearest rest area variables showed an illogical relationship in which the greater the distance, the lower the usage. The downstream city distance exhibited the only logical relationship amongst the distance variables. The proportion of trucks entering the rest area showed a fair correlation to rest area usage, which was expected. Rest area condition did not exhibit a strong correlation, although this is not surprising, as many rest area patrons are not likely to know the condition of a site beforehand and change their usage decision. Overall, the coefficients were all relatively low, suggesting a lack of strong correlations between the variables investigated and the rest area usage.

Table 24: Correlation Coefficients between Rest Area Usage and Study Variables (High-Volume Interstate)

Variable	**Correlation Coefficient**
Nearest upstream area	-0.278
Nearest upstream city	-0.038
Nearest downstream area	-0.24
Nearest downstream city	0.174
% trucks	0.316
Rest area condition	0.052

Low-Volume Interstate: Table 25 presents the correlation coefficients for rest area usage, as expressed in the relationship between percent entering and different distance, truck proportion and condition variables for the low-volume interstate category. The strongest relationship identified was related to the nearest upstream rest area distance variable, while the weakest relationship was related to facility condition. The upstream and downstream city distance variables exhibited weaker relationships relative to the upstream and downstream rest area distance variables. The city distance variable relationships were both found to be negative, again contradicting research hypotheses that the further the distance between a rest area and the nearest city, the higher the usage would be. The correlation between the mainline truck proportion and usage was also found to be negative. This contradicted the expectation that a higher proportion of trucks would result in higher usage. This class of interstate highways showed weaker correlations overall compared to the high-volume interstate category.

Table 25: Correlation Coefficients between Rest Area Usage and Study Variables (Low-Volume Interstate)

Study Variable	**Correlation Coefficient**
Nearest upstream area	0.224
Nearest upstream city	-0.154
Nearest downstream area	0.170
Nearest downstream city	-0.120
% trucks	-0.158
Rest area condition	-0.076

High-Volume Arterial: Table 26 presents the correlation coefficients for rest area usage, as expressed in the relationship between percent entering and different distance, truck proportion, condition and weigh station variables for the high-volume arterial category. Several low coefficients suggested that the relationship between the variables and the rest area usage was weak. The upstream and downstream rest area distance variables exhibited a stronger correlation, which was expected. The upstream and downstream city distance variables exhibited weaker and illogical correlations. Rest area condition exhibited a weak correlation with rest area usage, which based on previous results, was expected. The presence of a weigh station in operation also showed a slight correlation with the usage relative to all other variables in this category.

Table 26: Correlation Coefficients between Rest Area Usage and Study Variables (High-Volume Arterial)

Independent Variable	**Correlation Coefficient**
Nearest upstream area	0.557
Nearest upstream city	-0.119
Nearest downstream area	0.488
Nearest downstream city	-0.499
% trucks	-0.455
Condition	0.285
Weigh station Operation	0.314

<u>Low-Volume Arterial:</u> Table 27 presents the correlation coefficients for rest area usage, as expressed in the relationship between percent entering and different distance, truck proportion, condition and weigh station variables for the low-volume arterial category. All four distance variables show a weak relationship with rest area usage. The downstream city distance exhibited the only logical correlation among the distance variables. The percentage of trucks relative to rest area usage also exhibited a slightly positive relationship. The condition variable exhibited a slight logical relationship with

rest area usage on low volume arterials and represented the strongest correlation relative to all other study variables. The presence of a weigh station in operation also showed a weak logical relationship. The presence of a visitor information center was removed from this analysis, as only one rest area included this feature.

Table 27: Correlation Coefficients between Rest Area Usage and Study Variables (Low-Volume Arterial)

Independent variable	**Correlation coefficients**
Nearest upstream area	-.028
Nearest upstream city	-.040
Nearest downstream area	-.144
Nearest downstream city	.204
% trucks	.265
Rest area condition	.343
Weigh station operation	.199

Linear Regression

Linear regression was employed to develop models that could be used by MDT in estimating rest area usage based on the expected mainline traffic. Variables initially considered in the modeling process included:

- X_1 = Weekend/Weekday – (0 for a weekday, 1 for a weekend day)
- X_2 = Day/Night – Nominal variable (0 during the day, 1 during the night time designated as from 10 p.m. to 6 a.m.)
- X_3 = Nearest upstream rest area – the distance to the nearest upstream rest area facility, in miles
- X_4 = Nearest upstream city - the distance to the nearest upstream city providing basic services 24/7 including parking and restrooms, in miles

- X_5 = Nearest downstream rest area – the distance to the nearest downstream rest area facility, in miles
- X_6 = Nearest downstream city - the distance to the nearest downstream city providing basic services 24/7 including parking and restrooms, in miles
- X_7 = Rest area condition – the overall condition of the rest area facility (1=poor, 2=fair, 3=good), provided by MDT
- X_8 = % trucks – the proportion of commercial vehicles in the mainline traffic stream
- X_9 = Weigh station – the presence of a weigh station in operation (0 if no, 1 if yes)
- X_{10} = Visitor information center – the presence of a visitor information center (0 if no, 1 if yes)

Initially, the researchers intended to establish two separate models for each category of rest area: one to determine the percentage of hourly mainline counts entering the rest area and the second to determine the percentage of AADT entering the rest area. The model which fit the data best would be selected and recommended for use to MDT. During the course of modeling however, neither mainline traffic measure provided strong models for estimating rest area usage. Consequently, only the results of the hourly mainline entering models are presented in the following sections to present the reader with the overall process employed in completing this portion of the work. Complete details are provided for the first category (high-volume interstate), with brief summaries for the remaining categories provided.

High-Volume Interstate: As stated in the introduction to this section, linear regression was performed on the raw data for each rest area category. The results of this initial analysis produced the model presented in

Table 28:

Table 28: High-Volume Interstate Raw Regression Results

Variable	Constant	p-value
Intercept	11.065	<0.001
Weekend/weekday	0.235	0.445
Day/Night	0.733	<0.001
Nearest upstream area	-0.071	<0.001
Nearest upstream city	0.001	0.704
Nearest downstream area	-0.064	<0.001
Nearest downstream city	0.071	<0.001
Condition	0.641	<0.001
% trucks	0.141	<0.001

The variables X_1 through X_8 in this model correspond to those presented in the previous section. The R^2 value (the coefficient of determination, a relative measure of the strength of the model) of 0.192 indicated that this was a very weak model. Additionally, several of the variables exhibited relationships contrary to the hypotheses of the research team (i.e. nearest upstream and downstream rest area distance variables), as discussed in previous sections.

Based on these initial regression results, it was determined that the overall dataset required more verification for unusual observations. To eliminate outliers, observation hours with a percent of rest area usage greater than 60 percent were reduced to 60 percent at the greatest. This was done out of the view that completely excluding these hours from analysis would bias the results in favor of daytime hours. For any hour with a value of greater than 60 percent, that value of percent rest area usage was replaced with an average of the hour before and after. For example, if a data point at 9 p.m. was found to be above 60 percent, an average of the 8 p.m. hour and the 10 p.m. hour was found and replaced the 9 p.m. value. This procedure was primarily applied to the low volume arterial category, as that data produced the highest number of hours with high usage (i.e. low mainline volume with a high number of vehicles entering the rest area). This aggregation of data was performed only as part of the regression analysis and was not done for other parts of this research. This alteration of the data did not result in any significant change in the high-volume interstate category, as this group did not produce any observations above the 60 percent usage threshold.

A second approach applied to the data was the merging of nighttime hours into an averaged value (12 midnight-6 a.m.). This was completed to address issues of variability in the data. Again, during the nighttime hours, low traffic volumes often led to higher observations of rest area usage which were not entirely representative of an average condition. The resulting linear regression model for the high-volume interstate category using an averaged 12 a.m.-6 a.m. value is presented in Table 29:

Table 29: High-Volume Interstate Average Night Regression Results

Variable	**Constant**	**p-value**
Intercept	11.065	<0.001
Weekend/weekday	0.235	0.194
Day/Night	0.733	<0.001
Nearest upstream area	-0.071	<0.001
Nearest upstream city	0.001	0.241
Nearest downstream area	-0.064	<0.001
Nearest downstream city	0.071	<0.001

Condition	0.641	<0.001
% trucks	0.141	<0.001

The variables X_1 through X_8 in this model again correspond to those presented earlier. This model produced an R square value of 0.259, a slight improvement from the previous model. The values of the model constants remained exactly the same, but the p-values (probabilities) were slightly different. However, the nearest upstream and downstream rest area distance variables were once again found to exhibit relationships contrary to research hypotheses.

Recall that rest area planners design for a peak hour traffic volume. Therefore, in an attempt to further reduce the hourly variation in the data, only the hours during the observed peak period of rest area usage were considered. Based on observations made during the characterization analyses performed earlier (Characterization section), the hours between 9 a.m. and 4 p.m. were selected to represent the peak period. This removed the day/night study variable, X_2 from the subsequent model. The resulting peak period model is presented in Table 30:

Table 30: High-Volume Interstate Peak Regression Results

Variable	**Constant**	**p-value**
Intercept	6.134	<0.001
Weekend/weekday	0.053	0.707
Nearest upstream area	-0.067	0.821
Nearest upstream city	0.053	<0.001
Nearest downstream area	-0.079	<0.001
Nearest downstream city	0.072	<0.001
Condition	1.916	<0.001
% trucks	0.305	<0.001

This model produced an R square value of 0.441, a significant improvement from the previous models. Given these results, only the peak period data was considered beyond this point.

The next data consideration was the weigh station variable. It was decided that only the hours in which the weigh station was in operation should be given a value of 1. This resulted in the exclusion of the weigh stations located at the Bad Route, Broadus, and Troy sites, as these weigh stations were only used by law enforcement entities when necessary and not open during data collection periods at those sites. Similarly, only one rest area in Montana (Broadus) housed a visitor information center; consequently this variable was removed from the analysis.

In light of the model results related to the distance variables employed, the researchers also combined these variables together into two categories. Following these changes, a number of new variables were developed, including:

- X_{11} and X_{12}= Nearest upstream (shortest of upstream area and upstream city) and nearest downstream (shortest of downstream area and city)
- X_{13} and X_{14} = Nearest rest area (shortest of upstream and downstream rest area) and nearest city (shortest of upstream and downstream city)
- X_{15} = Nearest stopping opportunity (shortest of all distances)

These changes resulted in the development of three new models. The first model incorporated the peak period, nearest upstream and nearest downstream distance variables. The second model incorporated the peak period, nearest rest area and nearest city variables. The third model incorporated the peak period and shortest distance variables. The resulting models (in order), are presented in Table 31.

Using the nearest rest area and city variables (the second model) provided the highest R square value (0.438) however both distance variables gave negative constants. This suggested that usage decreased as these distances increased, contradicting expectations. Using the nearest upstream and downstream distances provided the strongest logical model. The remaining models produced R square values of 0.438 (first model) and 0.322 (third model) respectively.

Table 31: High-Volume Interstate Combined Distances Regression Results

Variable	**Constant**	**p-value**
Intercept	-18.030	<0.001
Weekend/weekday	0.009	0.540
Nearest upstream	0.145	<0.001
Nearest downstream	0.159	<0.001
Condition	3.964	<0.001
% trucks	0.636	<0.001
Intercept	23.441	<0.001
Weekend/weekday	0.037	0.712
Nearest area	-0.280	<0.001
Nearest city	-0.117	<0.001
Condition	-0.821	<0.001
% trucks	0.191	<0.001
Intercept	-9.461	<0.001
Weekend/weekday	0.019	0.685
Shortest distance	0.141	<0.001
Condition	2.731	<0.001
% trucks	0.611	<0.001

It was next considered that the models might be biased to the control stations based on the extended data collection at these sites (control stations were collected for approximately ten weeks in 2009 while each coverage station were collected for approximately one week). Therefore, one week of control station data was selected to match the sample station data in each category.

The week of usage data from the control station was selected by considering a time period approximately in the middle of the 2009 data collection effort for all sites in the high-volume interstate category. This resulted in a model with only one week of data of control station data employed (Greycliff EB). This resulted in the first model presented in Table 32 with an R square of 0.537, once again an improvement. When the one week control station count data was used in combination with the upstream and downstream distance variables (the second model in Table 32), the R square value deteriorated slightly to 0.512. Next, a model was developed using the one week control station count data with the nearest rest area and city distance variables. The resulting model (third model in Table 32) produced an improved R square value of 0.582. Finally, a model incorporating the one week control station count data and the shortest distance variable was developed. This model (the final model presented in Table 32) produced an R square value of 0.449, a significant deterioration over the results of the previous three models.

Most of the interstate rest areas serve one direction of travel, therefore two rest area facilities are often employed at one site. However, four state-maintained interstate rest areas in Montana (Anaconda, Bozeman, Bad Route, and Sweetgrass) serve both directions of interstate travel, employing one facility at an interchange. These sites showed a lower percent rest area usage relative to the other interstate sites due to the combined mainline traffic volumes taken into account as utilizing the site. Therefore, it was hypothesized that removing these sites from the regression analysis would improve the results for the two interstate categories. The resulting models for the high-volume interstate category incorporating the four distance variables, the nearest upstream and downstream distance variables, the nearest rest area and city distance variables, and shortest distance variable were as presented in Table 33.

Table 32: High-Volume Interstate One Week Control Regression Results

Variable	**Constant**	**p-value**
Intercept	0.373	<0.001
Weekend/weekday	0.013	0.921
Nearest upstream area	-0.069	0.015
Nearest upstream city	0.025	0.008
Nearest downstream area	-0.043	0.132
Nearest downstream city	0.071	<0.001
Condition	2.510	<0.001
% trucks	0.451	<0.001
Intercept	-17.451	<0.001
Weekend/weekday	-0.049	0.882
Nearest upstream	0.096	<0.001
Nearest downstream	0.128	<0.001
Condition	3.878	<0.001
% trucks	0.698	<0.001
Intercept	18.826	<0.001
Weekend/weekday	-0.006	0.961
Nearest area	0.253	0.001
Nearest city	-0.174	<0.001
Condition	-0.518	<0.001
% trucks	0.344	<0.001
Intercept	-9.562	<0.001
Weekend/weekday	-0.026	0.948
Shortest distance	-0.042	0.048
Condition	2.199	<0.001
% trucks	0.779	<0.001

Table 33: High-Volume Interstate Dual-Only Regression Results

Variable	**Constant**	**p-value**
Intercept	4.266	0.001
Weekend/weekday	0.006	0.545
Nearest upstream area	-0.049	<0.001
Nearest upstream city	0.069	<0.001
Nearest downstream area	-0.071	<0.001
Nearest downstream city	0.076	<0.001
Condition	4.689	<0.001
% trucks	0.158	<0.001
Intercept	-15.763	<0.001
Weekend/weekday	-0.023	0.410
Nearest upstream	0.136	<0.001
Nearest downstream	0.144	<0.001
Condition	5.929	<0.001
% trucks	0.479	<0.001
Intercept	-8.512	0.004
Weekend/weekday	-0.010	0.473
Nearest area	-0.017	0.543
Nearest city	0.206	<0.001
Condition	6.647	<0.001
% trucks	0.315	<0.001
Intercept	-10.345	<0.001
Weekend/weekday	-0.007	0.451
Shortest distance	0.217	<0.001
Condition	6.575	<0.001
% trucks	0.369	<0.001

The resulting R square values for these models were 0.517, 0.498, 0.483 and 0.461, respectively. As these values indicate, none of the models was an improvement over previous results. After all possibilities to screen the percent usage data were exhausted, the data for the peak period with the adjusted weigh station variable was used for remaining modeling. This eliminates any potential effects of the night hours on these analyses which would not be considered in design. A nominal variable was also introduced to account for the peak period around the midday lunch period in which rest area usage was expected to be the greatest (called the lunch peak). Based on previous examination of the data, this period was determined to be from 10 a.m. to 12 noon.

Transformations were next considered in an attempt to increase the R square value of the models. Appropriate transformations were selected through a plotting of the respective data and developing best-fit lines to the plots. These plots are presented in **Error! Reference source not found.**, with the resulting transformation presented in

Table 34.

Table 34: High-Volume Interstate Transformations

Independent variable	**Transformation**
Nearest upstream area	Square
Nearest upstream city	None
Nearest downstream area	Square
Nearest downstream city	$x^{.3022}$
% trucks	$x^{1.6551}$
Nearest rest area	Square
Nearest city	$x^{0.1649}$
Nearest upstream	None
Nearest downstream	$x^{0.3425}$
Shortest	$x^{0.1691}$

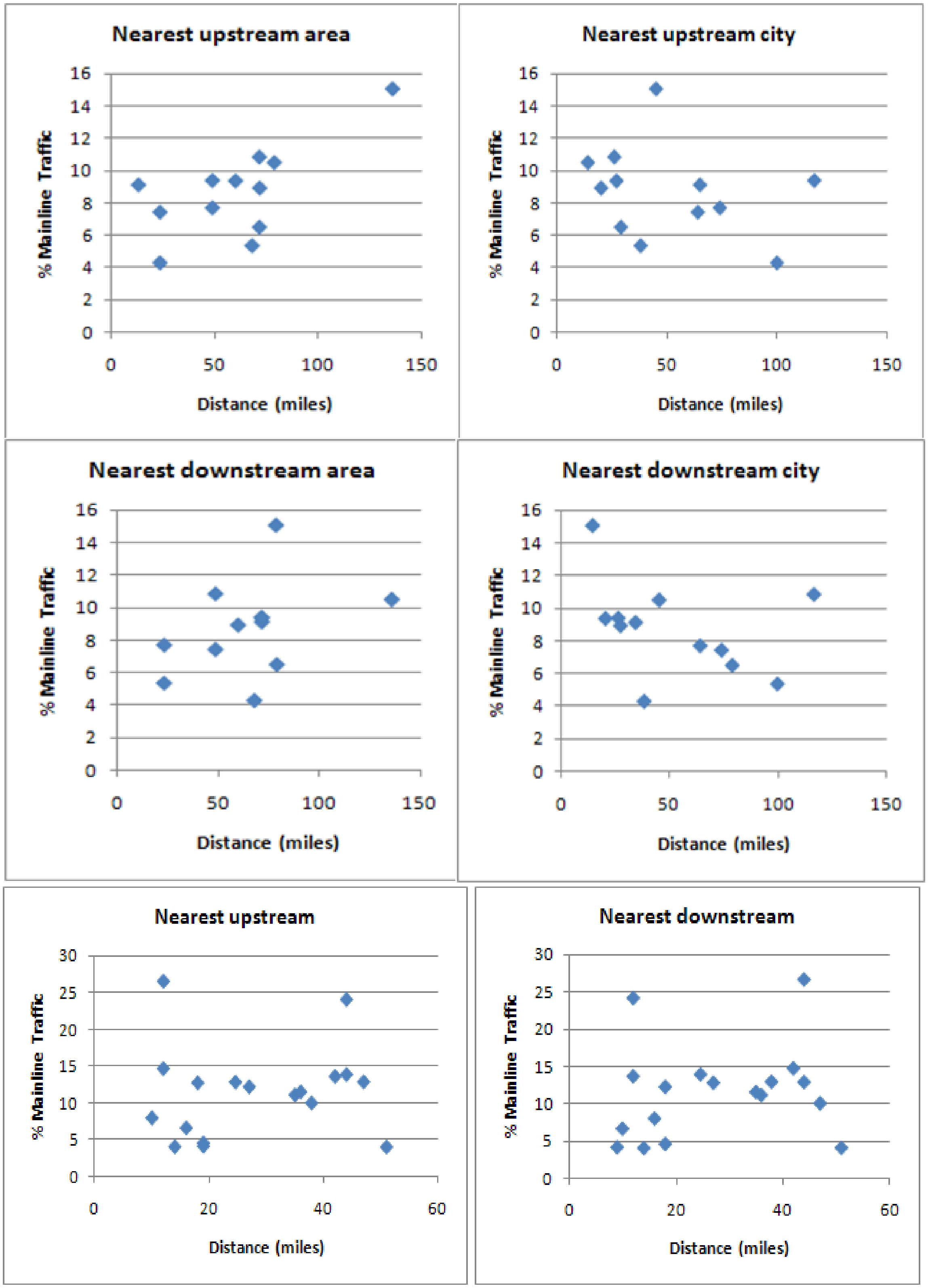
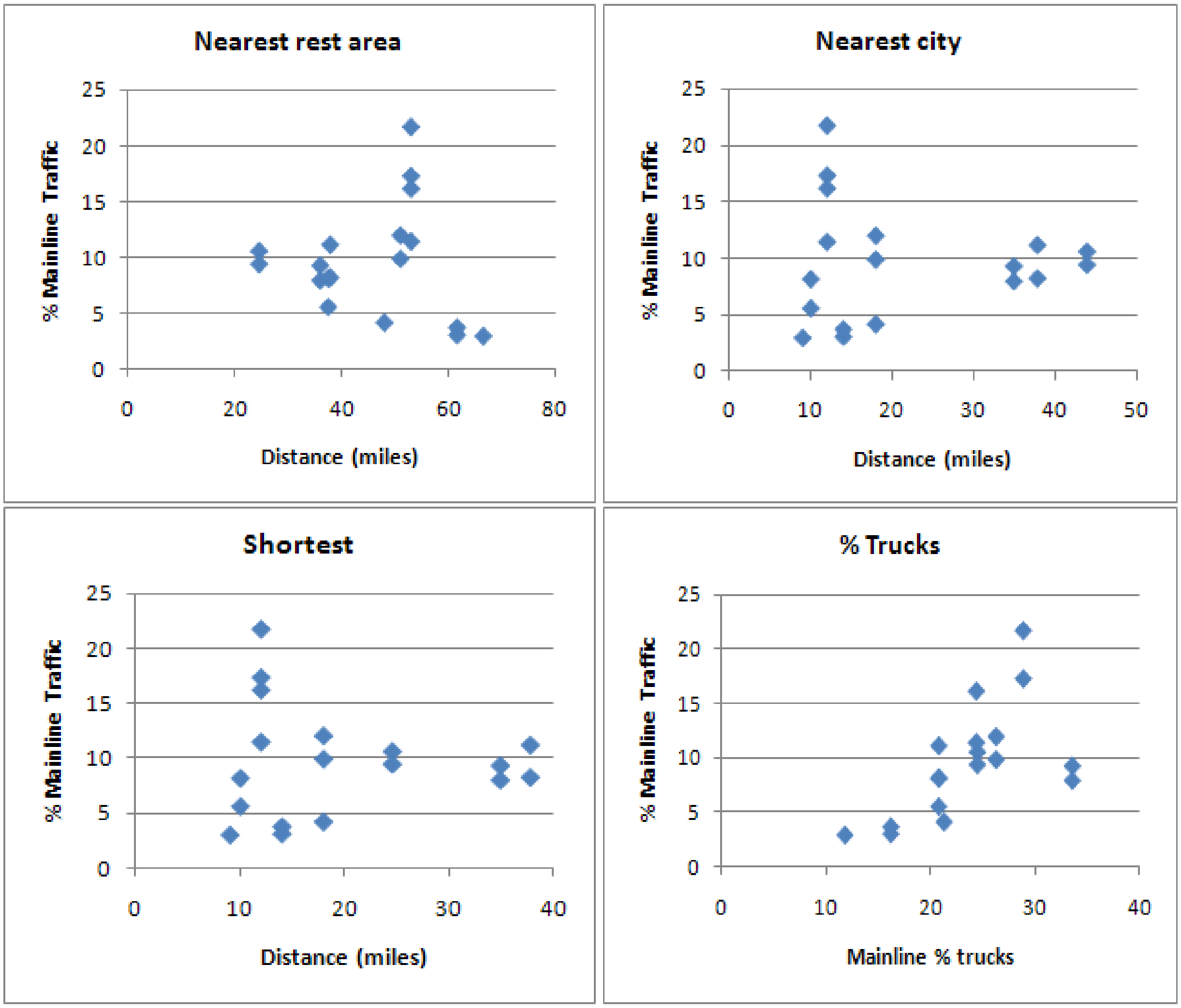


Figure 53: High-Volume Interstate Transformation Plots



Error! Reference source not found. (cont'd): High-Volume Interstate Transformation Plots

Using the results of the transformation analysis, the statistical software package SPSS was used to determine which transformations resulted in significant improvements of the models. The criterion used to determine variable significance was based on the p-value (probability) of the variable being less than 0.05 and the R square improvement being greater than 0.015. Any study variable exhibiting an illogical relationship with rest area usage was removed during this process. The final model for estimating rest area usage on high-volume interstates was:

- $Y = -18.170 + 1.495 * (\text{lunch peak}) + 0.096 * X_{11} + 0.128 * X_{12} + 3.885 * X_7 + 0.700 * X_8$

The final model developed for high-volume interstates included the lunch period variable, the distance to the nearest upstream and downstream stopping opportunity, the condition of the rest area, and the mainline truck proportion. The condition had a relatively large effect on the usage, supported by the high value of the coefficient (3.885). This was an interesting result given the observations made while performing the characterizations of rest areas. An R square value of 0.525 suggested that the model explains approximately 52.5 percent of the variability within the data. While this is model is neither weak nor strong, it was not believed to be strong enough to warrant being employed to estimate rest area usage in the future.

Low-Volume Interstate: The initial model developed for this category (presented in .

Table **35**) produced an R square of 0.101, suggesting much processing of the data in this group was required to produce acceptable models for estimating rest area usage for planning purposes. When the night hours were averaged and all values above 60 percent rest area usage were reduced, the R square of the model improved to 0.184, with the resulting model presented in Table 36.

Table 35: Low-Volume Interstate Raw Regression Results

Variable	**Constant**	**p-value**
Intercept	2.662	0.252
Weekend/weekday	0.170	0.486
Day/Night	-1.942	<0.001
Nearest upstream area	0.054	<0.001
Nearest upstream city	-0.014	0.068
Nearest downstream area	0.001	0.880
Nearest downstream city	-0.021	0.004
Condition	4.391	<0.001
% trucks	-0.151	<0.001
Weigh station	-5.706	<0.001

Table 36: Low-Volume Interstate Average Night Regression Results

Variable	**Constant**	**p-value**
Intercept	-0.784	0.620
Weekend/weekday	0.128	0.441
Day/Night	-2.387	<0.001
Nearest upstream area	0.061	<0.001
Nearest upstream city	-0.002	0.760
Nearest downstream area	0.011	0.001
Nearest downstream city	-0.004	0.445
Condition	4.444	<0.001
% trucks	-0.125	<0.001
Weigh station	-6.665	<0.001

After considering only the peak hours and adjusting the weigh station variable, the R square value again increased to 0.271 (only the model with the highest R square value is presented in Table 37 for brevity).

Table 37: Low-Volume Interstate Peak Period Regression Results

Variable	**Constant**	**p-value**
Intercept	22.542	<0.001
Weekend/weekday	-0.405	0.136
Shortest distance	-0.413	<0.001
Condition	1.091	0.033
% trucks	-0.242	<0.001

Excluding the rest areas that served two directions of travel, the R square decreased to 0.234, suggesting the effects of the two non-dual sites (Bad Route and Sweetgrass) on the data set was negligible, with the model coefficients presented in Table 38. The value of the condition constant was removed because excluding these sites resulted in all values of the facility condition rating being equal (i.e. all sites in this category were given a rating of "fair"). This was different than what was observed in the high-volume interstate category, as removing single sites in that group increased the R square value significantly.

Table 38: Low-Volume Interstate Dual-Only Regression Results

Variable	**Constant**	**p-value**
Intercept	-3.866	0.005
Weekend/weekday	0.160	0.674
Nearest area	0.233	<0.001
Nearest city	0.220	<0.001
% trucks	-0.173	<0.001

Entering one week of data from the control station for this category (Divide SB), the R square value decreased to 0.156, with the resulting model presented in Table 39. Based on the R square values, this represents a significant deterioration from previous results.

Table 39: Low-Volume Interstate One Week Control Regression Results

Variable	**Constant**	**p-value**
Intercept	23.060	<0.001
Weekend/weekday	-0.121	0.744
Shortest distance	-0.431	<0.001
Condition	1.050	0.039
% trucks	-0.246	<0.001

To further improve the models, transformations were performed. These were once again determined through a plotting of the variables to select the appropriate transformation to apply. The plots employed are presented in Figure 53, while the resulting transformations applied are detailed in **Error! Reference source not found.**.

Table 40: Low-Volume Interstate Transformations

Independent variable	**Transformation**
Nearest upstream area	Square
Nearest upstream city	$x^{-0.0172}$
Nearest downstream area	None
Nearest downstream city	Square
% trucks	Square
Nearest rest area	None
Nearest city	Square
Nearest upstream	Square
Nearest downstream	Square
Shortest	Square

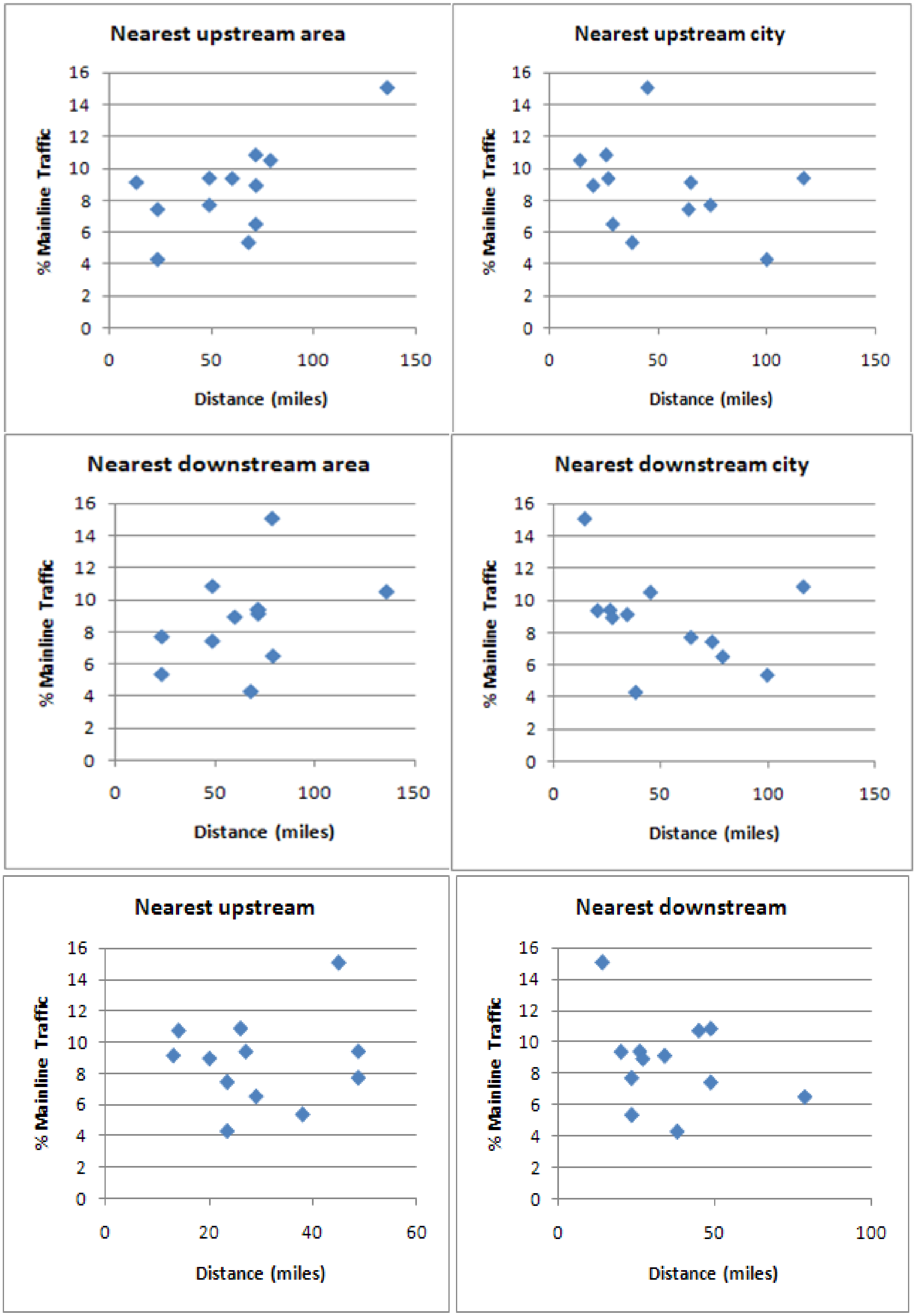


Figure 53: Low-Volume Interstate Transformation Plots

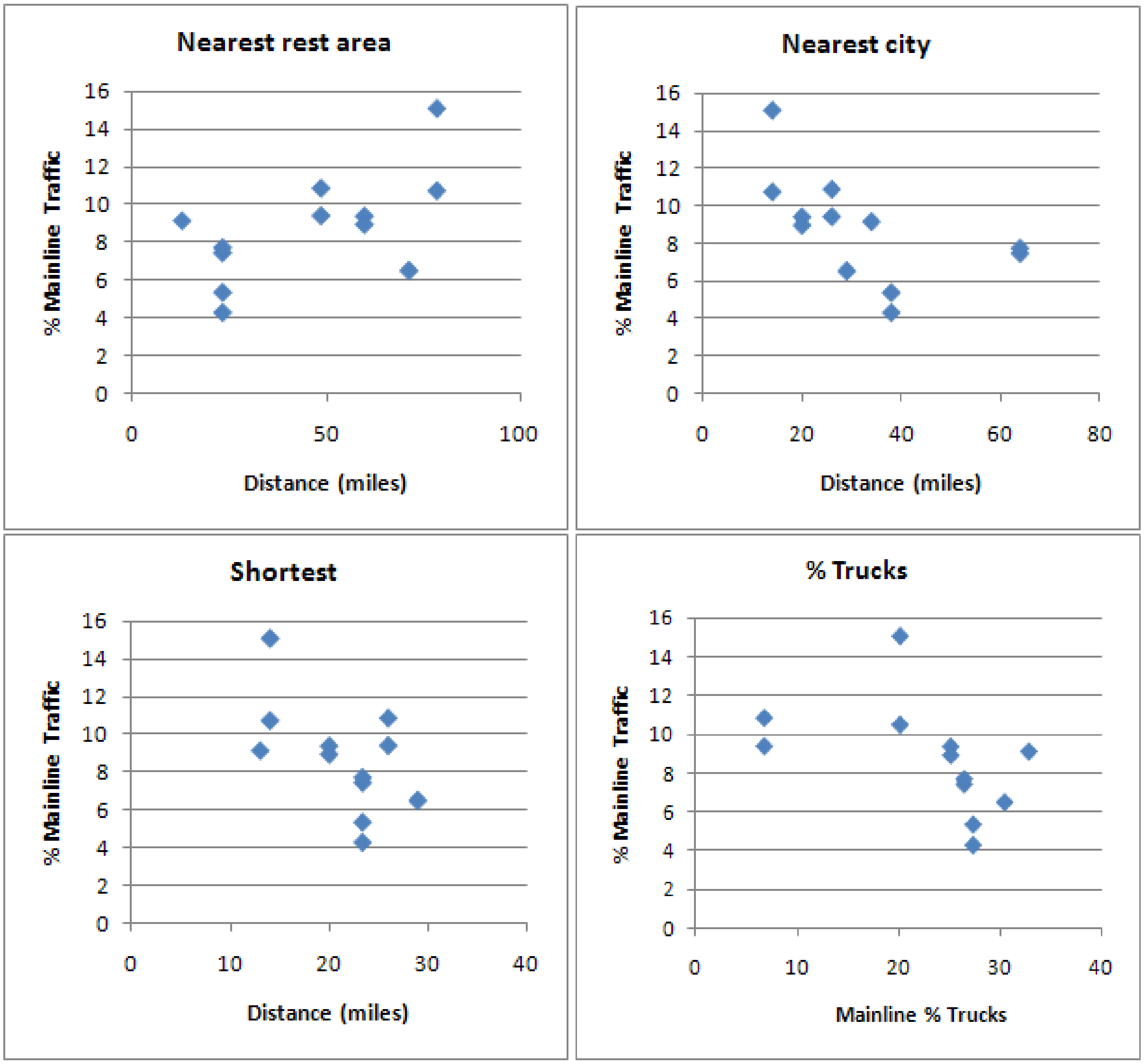


Figure 53 (cont'd): Low-Volume Interstate Transformation Plots

The final model developed to estimate rest area usage at rest areas on low-volume interstate highways was:

- $Y = -112.755 + 1.578*(\text{lunch peak}) + 1.186*X_{11} - 0.014*X_{11}^2 + 1.208*X_{12} - 0.015*X_{12}^2 + 29.462*X_7 + 3.870*X_8 - 0.118*X_8^2$

The final model developed included the lunch peak variable, the nearest upstream and downstream distances, the condition of the rest area, and the mainline truck proportion. The condition had an extremely large effect on the usage in this model (29.462) and also changed drastically from earlier regression attempts. The R square produced by this model of 0.320 suggested that approximately 32 percent of the variability within the data is explained by the model. This model was far weaker than those developed for rest areas on high-volume interstates. This result was not surprising, as early regression models suggested developing a strong model with the data from this category was unlikely.

<u>High-Volume Arterial:</u> The first regression model created for this category using only the raw data produced promising results relative to the other categories, with an R square value of 0.427. However, the statistical software being used in the analysis (SPSS) automatically removed several variables due to their violation of the tolerance criterion (in this case all distance variables). The tolerance criterion is a measure of multi-collinearity, or the phenomenon in which two or more predictor variables in a regression model are highly correlated. The resulting model showing the effects of this violation is presented in

Table 41. After reducing all rest area usage values below 60 percent, the R square again increased to 0.551, with the resulting constants provided in Table 42

Table **42**.

Table 41: High-Volume Arterial Raw Regression Results

Variable	**Constant**	**p-value**
Intercept	47.517	<0.001
Weekend/weekday	-0.346	0.098
Day/Night	-3.609	<0.001
Nearest upstream area	N/A	N/A
Nearest upstream city	N/A	N/A
Nearest downstream area	N/A	N/A
Nearest downstream city	N/A	N/A
Condition	-5.740	<0.001
% trucks	-2.286	<0.001
Weigh station	12.822	<0.001

Table 42: High-Volume Arterial Average Night Regression Results

Variable	**Constant**	**p-value**
Intercept	46.302	<0.001
Weekend/weekday	-.446	0.007
Day/Night	-3.686	<0.001
Nearest upstream area	N/A	N/A
Nearest upstream city	N/A	N/A
Nearest downstream area	N/A	N/A
Nearest downstream city	N/A	N/A
Condition	-5.398	<0.001
% trucks	-2.244	<0.001
Weigh station	12.346	<0.001

After considering only the peak period hours and adjusting the weigh station variable, the model provided in Table 43 gave an R square which increased to 0.610. Using only one week of data from the control station (Bridger), the model provided in

Table 44 saw the R square decrease significantly to 0.479. This had a larger effect on this category relative to other categories due to the low number of sites in this group.

Table 43: High-Volume Arterial Peak Combined Distance Regression Results

Variable	**Constant**	**p-value**
Intercept	25.860	<0.001
Weekend/weekday	-0.859	0.012
Shortest distance	-0.176	<0.001
Condition	N/A	N/A
% trucks	-1.116	<0.001
Weigh station	6.071	<0.001

Table 44: High-Volume Arterial Peak One Week Regression Results

Variable	**Constant**	**p-value**
Intercept	25.838	<0.001
Weekend/weekday	-2.701	0.003
Shortest distance	-0.173	0.001
Condition	N/A	N/A
% trucks	-1.101	<0.001
Weigh station	6.451	<0.001

To further improve the models, transformations were performed, which are presented in Table 45. None of these transformations had a significant effect on the R square value of the resulting model. Therefore, the transformations for this category were not considered further (note that the plots used to identify the transformation have also been excluded to be concise).

Table 45: High-Volume Arterial Transformations

Independent variable	**Transformation**
Nearest upstream area	None
Nearest upstream city	Square
Nearest downstream area	$x^{0.9214}$
Nearest downstream city	Square
% trucks	None
Nearest rest area	$x^{0.9214}$
Nearest city	Square
Nearest upstream	Square
Nearest downstream	Square
Shortest	Square

The final model developed for estimating rest area usage on high-volume arterials was of the form:

- $Y = -7.448 + 1.256*(\text{lunch period}) + 0.178*X_3 + 0.079*X_6 + 6.219*X_9$

This model included the lunch period variable, the distance to the nearest upstream rest area, the distance to the nearest downstream city, and the presence of an adjacent weigh station. It was the strongest model developed out of all categories, with an R square value of 0.640, suggesting that 64.0 percent of the variation within the data was explained by the model.

<u>Low-Volume Arterial:</u> The initial model employing raw data presented in Table 46 produced a weak model, with an R square value of 0.262.

Table 46: Low-Volume Arterial Raw Data Regression Results

Variable	Constant	p-value
Intercept	-10.435	0.002
Weekend/weekday	1.230	0.017
Day/Night	-1.598	0.001
Nearest upstream area	-0.086	0.147
Nearest upstream city	-0.078	0.013
Nearest downstream area	0.171	<0.001
Nearest downstream city	-0.181	0.002
Condition	13.520	<0.001
% trucks	0.165	0.463
Weigh station	-15.276	<0.001
Info	-8.302	<0.001

After reducing the rest area usage values below 60 percent and averaging the night hours as in previous sections, the model presented in Table 47

Table **47** improved significantly producing an R square value of 0.417.

Table 47: Low-Volume Arterial Averaged Night Regression Results

Variable	Constant	p-value
Intercept	-5.574	0.002
Weekend/weekday	1.152	<0.001
Day/Night	-2.736	<0.001
Nearest upstream area	-0.129	<0.001
Nearest upstream city	-0.048	0.005
Nearest downstream area	0.120	<0.001
Nearest downstream city	-0.123	<0.001
Condition	10.904	<0.001
% trucks	0.322	0.010
Weigh station	-12.799	<0.001
Info	-7.398	<0.001

After considering only the peak hours and adjusting the weigh station variable, the R square again improved to 0.609. The results of this model are provided in Table 48. This category included the only visitor information center (Broadus), which was removed from the analysis. After removing the visitor information center variable from the model, the R square decreased to 0.552 with the resulting model provided in Table 49.

Table 48: Low-Volume Arterial Peak Regression Results

Variable	**Constant**	**p-value**
Intercept	21.963	<0.001
Weekend/weekday	0.240	0.695
Nearest upstream area	-0.709	<0.001
Nearest upstream city	0.133	<0.001
Nearest downstream area	-0.245	<0.001
Nearest downstream city	0.331	<0.001
Condition	0.723	0.451
% trucks	2.434	<0.001
Weigh station	34.464	<0.001
Info	-14.702	<0.001

Table 49: Low-Volume Arterial Peak without Info Regression results

Variable	**Constant**	**p-value**
Intercept	24.140	<0.001
Weekend/weekday	0.182	0.775
Nearest upstream area	-0.633	<0.001
Nearest upstream city	-0.009	0.674
Nearest downstream area	-0.123	<0.001
Nearest downstream city	0.200	<0.001
Condition	1.359	0.171
% trucks	2.081	<0.001
Weigh station	31.51	<0.001

After considering only one week of data from the control station for this category (Emigrant), no significant change in the R square value was observed (0.559). To further improve the models, transformations were performed. These were once again determined through a plotting of the variables to select the appropriate transformation to apply. The plots employed are presented in Figure 54, while the resulting transformations applied are detailed in Table 50.

Table 50: Low-Volume Arterial Transformations

Independent variable	**Transformation**
Nearest upstream area	Square
Nearest upstream city	Square
Nearest downstream area	Square
Nearest downstream city	Square
% trucks	$x^{0.4048}$
Nearest rest area	Square
Nearest city	Square
Nearest upstream	Square
Nearest downstream	Square
Shortest	Square

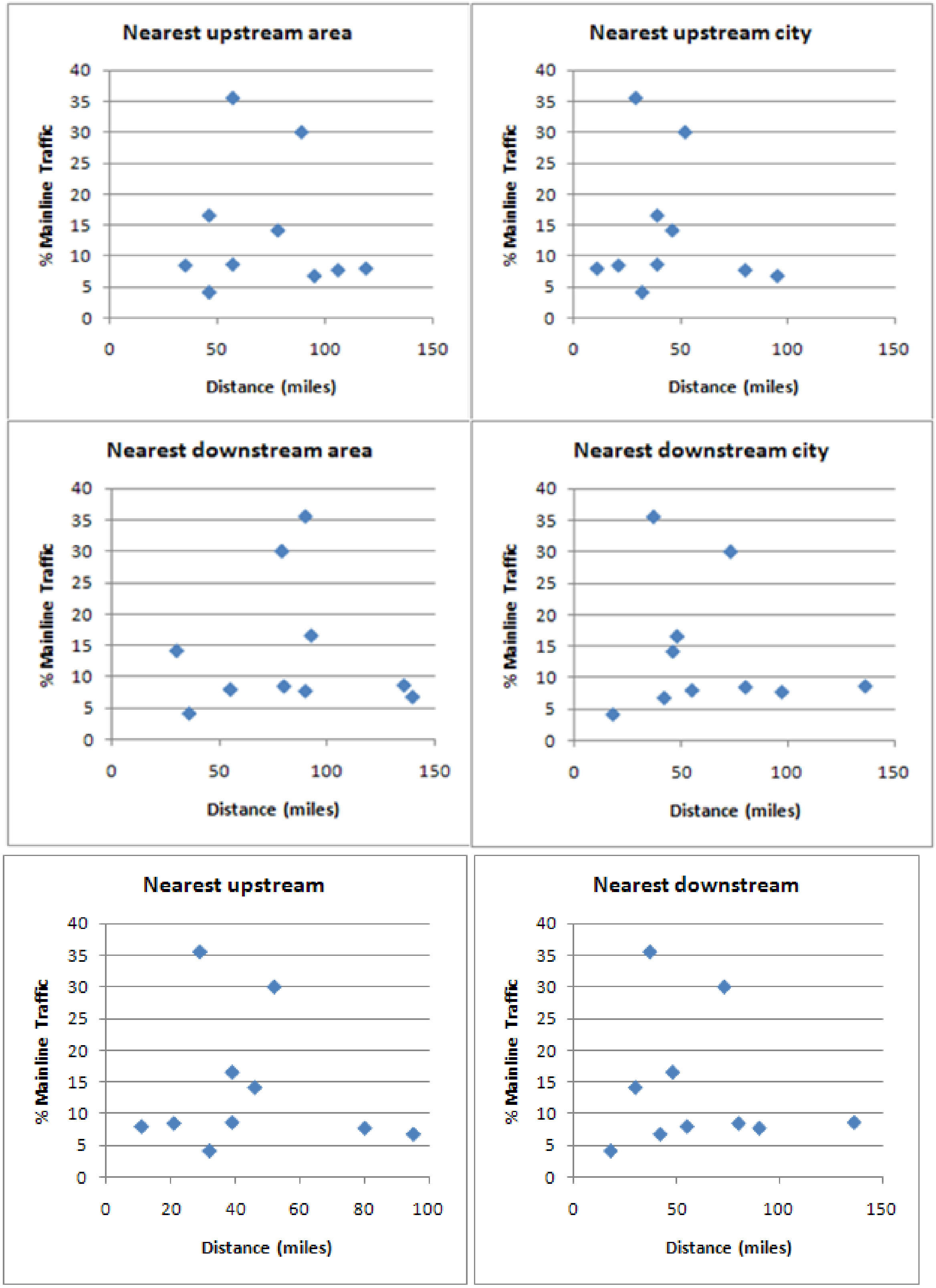


Figure 54: Low-Volume Arterial Transformation Plots

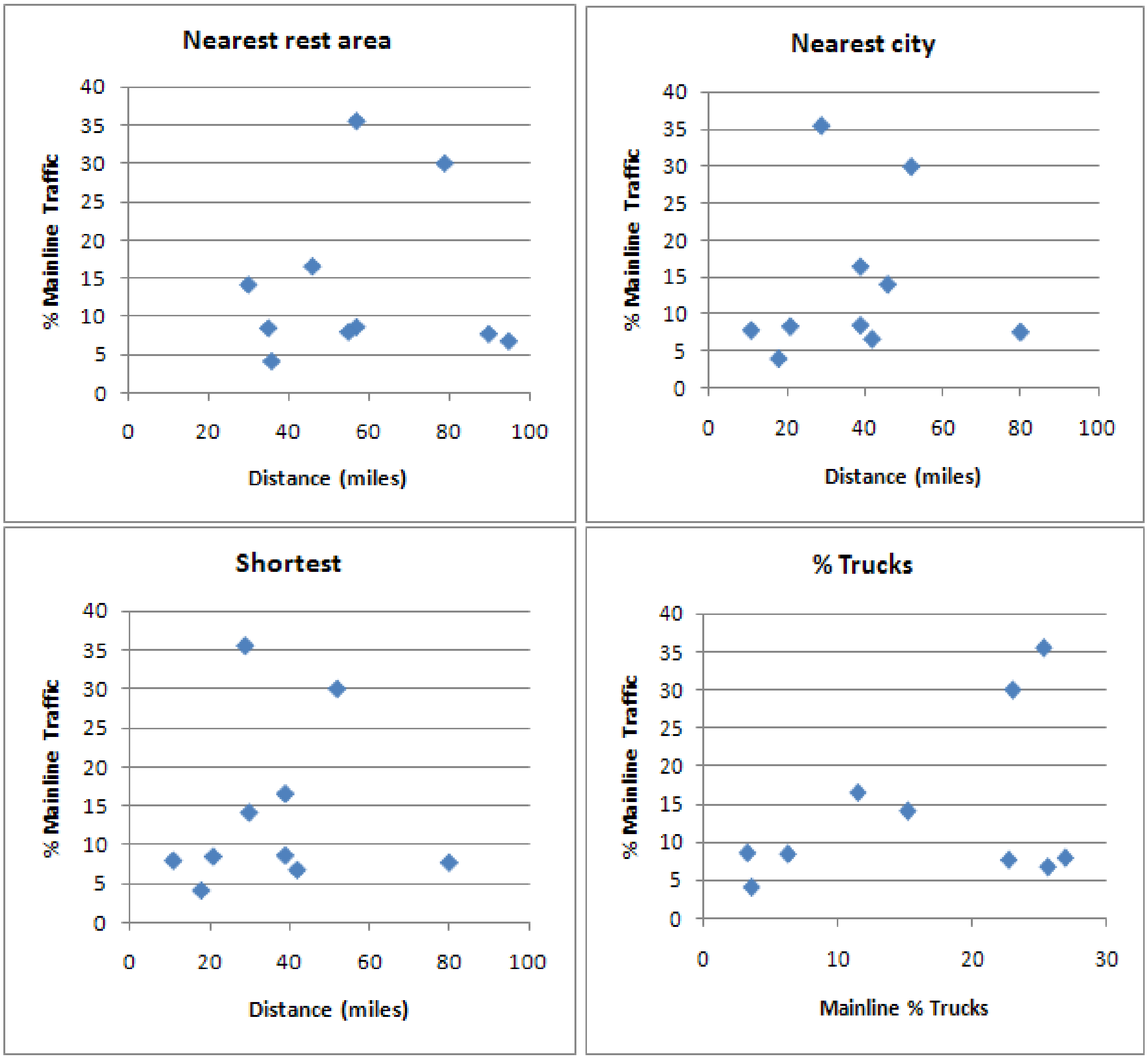


Figure 54 (cont'd): Low-Volume Arterial Transformation Plots

The final model developed for estimating rest area usage on rest areas on low-volume arterials in Montana was of the form:

- $Y = -19.308 + 1.161*(\text{lunch period}) + 0.980*X_{11} - 0.010*X_{11}^2 + 0.241*X_{12} - 0.002*X_{12}^2 + 22.762*X_9 + 0.604*X_8$

This model included the lunch period variable, the distance to the nearest upstream and downstream stopping opportunity, the presence of a weigh station, and the mainline truck proportion. The model produced an R square value of 0.516, indicating that approximately 51 percent of the variability within the data was explained by the model. This model, while neither weak nor strong, was not considered ideal for recommendation to MDT for use in modeling rest area usage at low-volume arterial sites.

Combined Categories: One additional regression analysis pursued was the combination of the two interstate categories together into one dataset. Similarly, the two arterial categories were also combined. This resulted in two data sets with which to investigate the effect of traffic levels on the rest area usage models. This increased the amount of data used to create the regression models and held the possibility of potentially producing stronger models.

The model produced by the combined interstate usage data was found to be extremely weak, producing an R square value of 0.051. While the arterial model produced a much higher R square of 0.446, combining categories was eliminated from further consideration based on these disappointing results.

The researchers also considered combining all available data together into one dataset and designating discrete variables for the mainline traffic level (0 = low-volume and 1 = high volume) and facility type (0 = arterial and 1 = interstate). After examining all possible combinations of the distance variables included in this research, the value of R square never rose above 0.14. Interestingly, the traffic level discrete variable was always found to be significant and negative (suggesting the value of percent usage decreases with increase in mainline traffic level), while the facility type variable was never found to be significant.

High-Volume Interstate Model Diagnostics: Descriptive statistics from the model are presented in Table 51 below. The high value and associated low significance of the F-statistic supports two conclusions: first that the variance explained by the model is not likely due to chance, and second using the model would provide better estimates of rest area usage than using the overall mean.

Table 51: High-Volume Interstate Model Descriptive Statistics

Adjusted R^2	**Standard error of estimate**	**F**	**Significance**
0.525	0.522	195.906	<0.001

The values of the coefficients produced by linear regression modeling are provided in Table 52. The t-statistic provides an estimate of whether the variable has a significant effect on the model. A t-statistic with a value greater than 2 is commonly associated with a significance less than 0.05 required in most engineering applications, suggesting a 95% confidence that this variable is significant not due to chance. Further examination of the standardized coefficients suggests the mainline % trucks has the greatest effect on usage for the high-volume interstate category.

Table 52: High-Volume Interstate Model Coefficients

	Unstandardized Coefficients		**Standardized Coefficients**		
Constant	**Coefficient**	**Standard Error**	**Beta**	**t-statistic**	**Significance**
Intercept	-18.170	1.023		-17.762	<0.001
Lunch Peak	1.495	0.303	0.114	4.930	<0.001
Nearest Upstream Distance	0.096	0.013	0.196	4.560	<0.001
Nearest Downstream Distance	0.128	0.013	0.272	10.041	<0.001
Facility Condition Rating	3.885	0.226	0.484	17.170	<0.001
Mainline % Trucks	0.700	0.028	0.589	24.701	<0.001

There are many assumptions made when modeling data with linear regression. A brief description of each assumption as well as methods of checking these assumptions is described next.

The first assumption is a linear relationship between the independent variables and the dependent variable. Linearity can also be achieved by transforming the independent variables. This is usually checked by using several different plots, including plots of all independent variables vs. the residuals and plots of model predicted values vs. the residuals. These are to be examined to determine whether any curvilinear trends are present between the dependent variable and any of the independent variables.

Figure 55 plots the residuals versus the predicted values. While a curvilinear pattern may exist between the residuals and predicted values, lack of an obvious trend suggests a linear relationship.

Figure 56 through Figure 60 present graphs plotting the residuals against each of the independent variables used to develop the model. The relationship between the residuals and the nearest upstream distance appears to have waves, suggesting this relationship may be curvilinear. A similar pattern also occurs for the nearest downstream distance. The facility condition rating does not appear to have a curvilinear pattern. The mainline % trucks may have a parabolic relationship with the model residuals. No pattern can be discerned for the lunch peak variable because it is a binary variable (0 or 1).

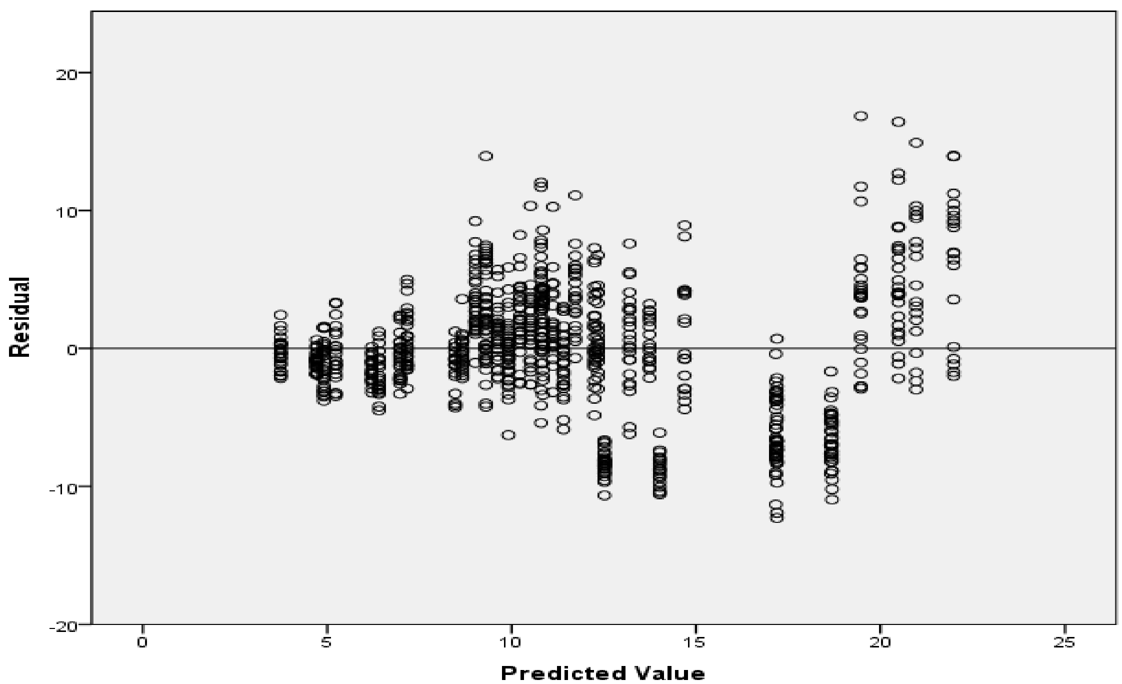


Figure 55: High-Volume Interstate: Residual vs. Predicted Value

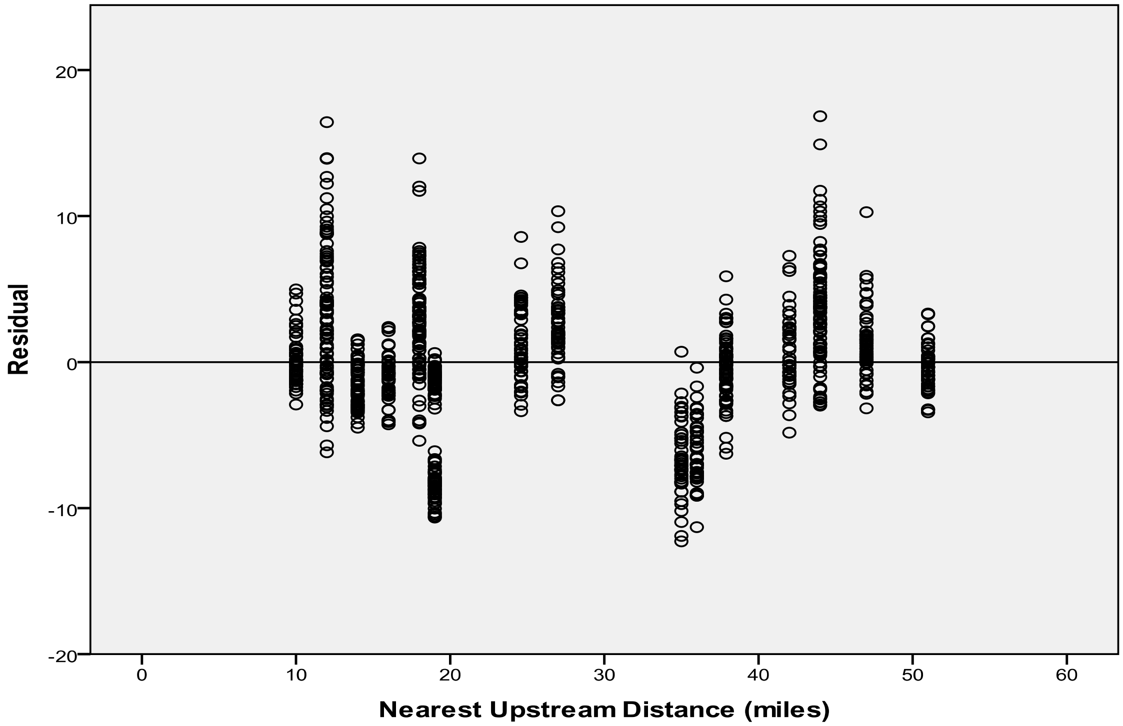


Figure 56: Residual vs. Nearest Upstream Distance

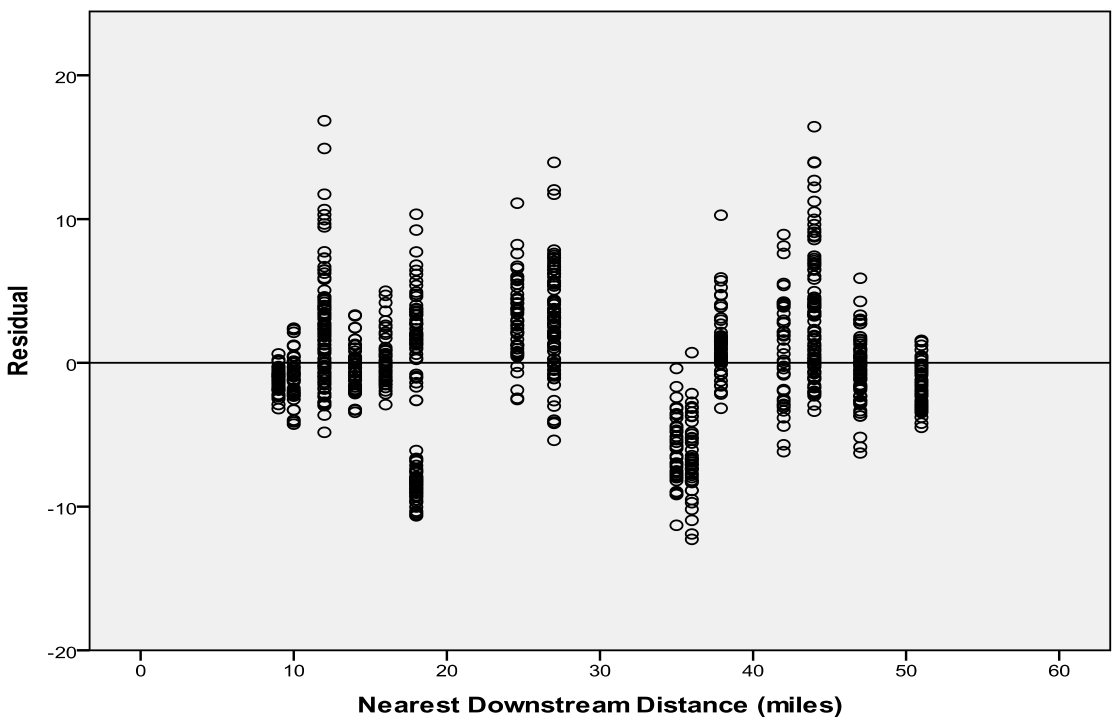


Figure 57: Residual vs. Nearest Downstream Distance

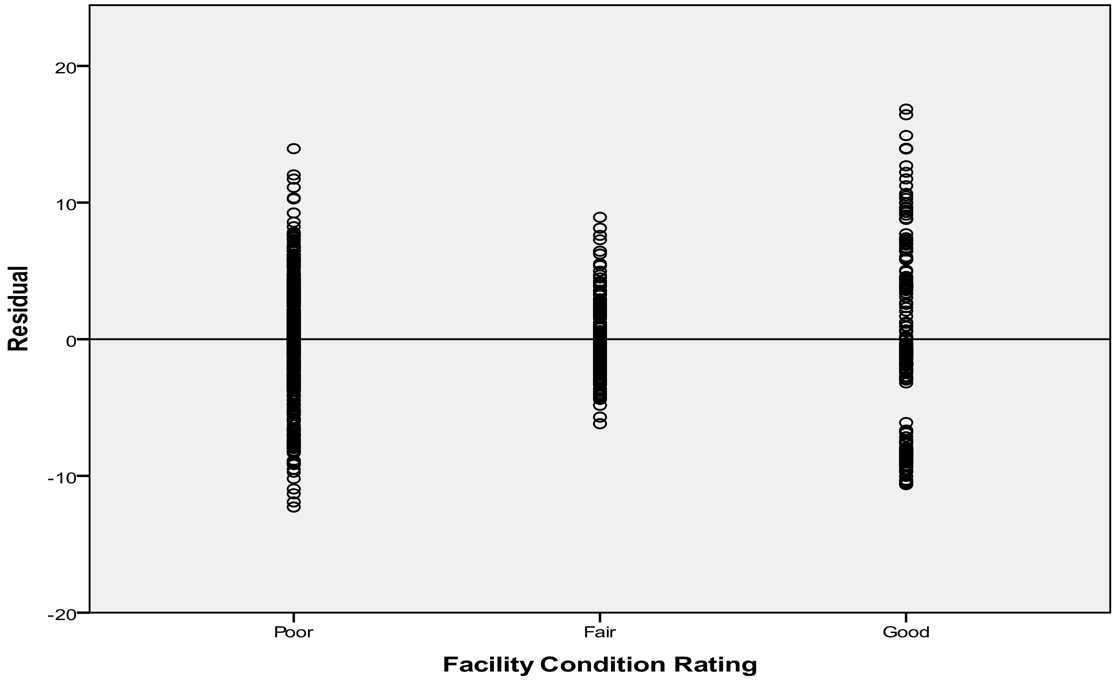


Figure 58: Residual vs. Facility Condition Rating

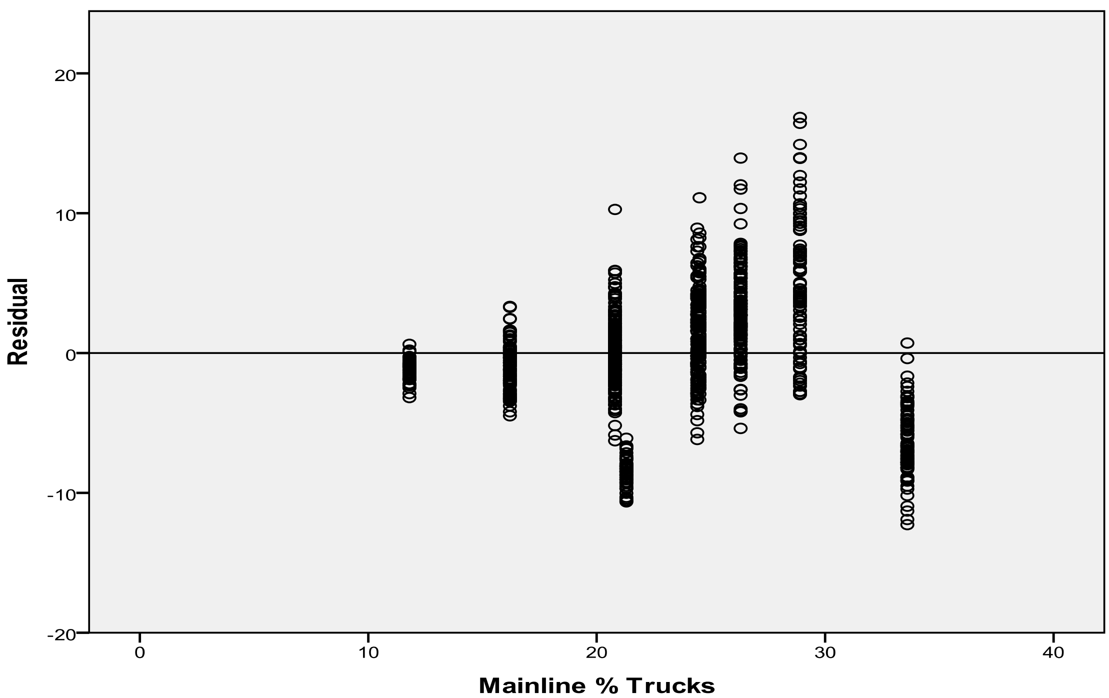


Figure 59: Residual vs. Mainline % Trucks

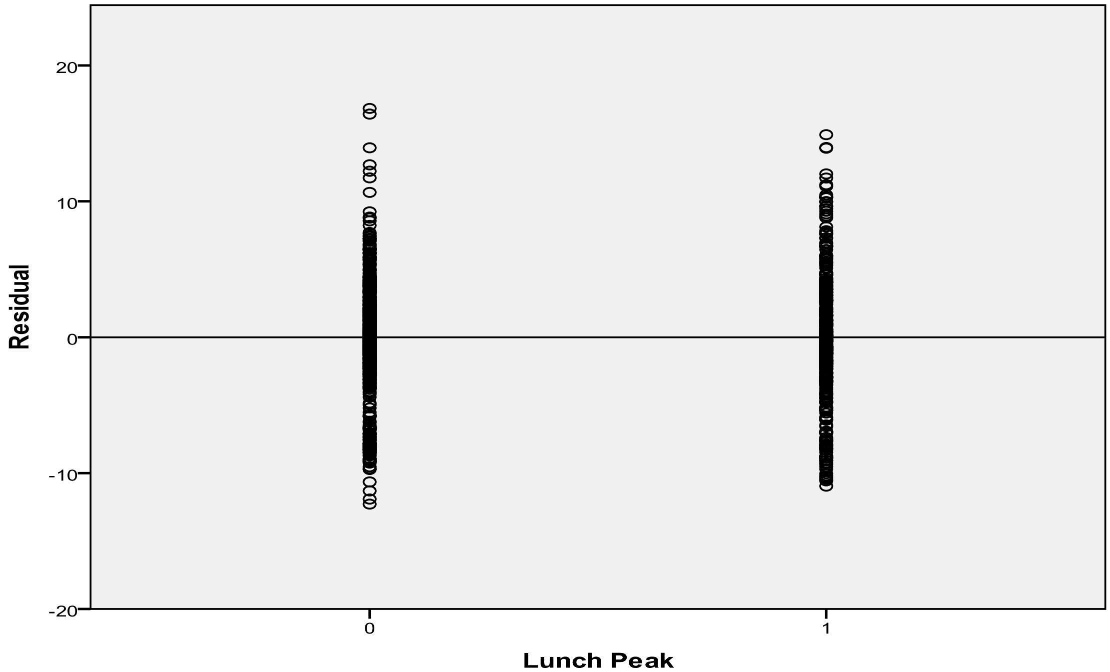


Figure 60: Residual vs. Lunch Peak

The next assumption states that the residuals must be approximately normally distributed. The expected value (mean) of the normally distributed residuals should also be equal to zero. These assumptions can be checked using a variety of informal plots. Summary statistics of the residuals can be used to obtain an informal conclusion. A histogram of the disturbances should reveal a bell-shape commonly associated with a normal distribution.

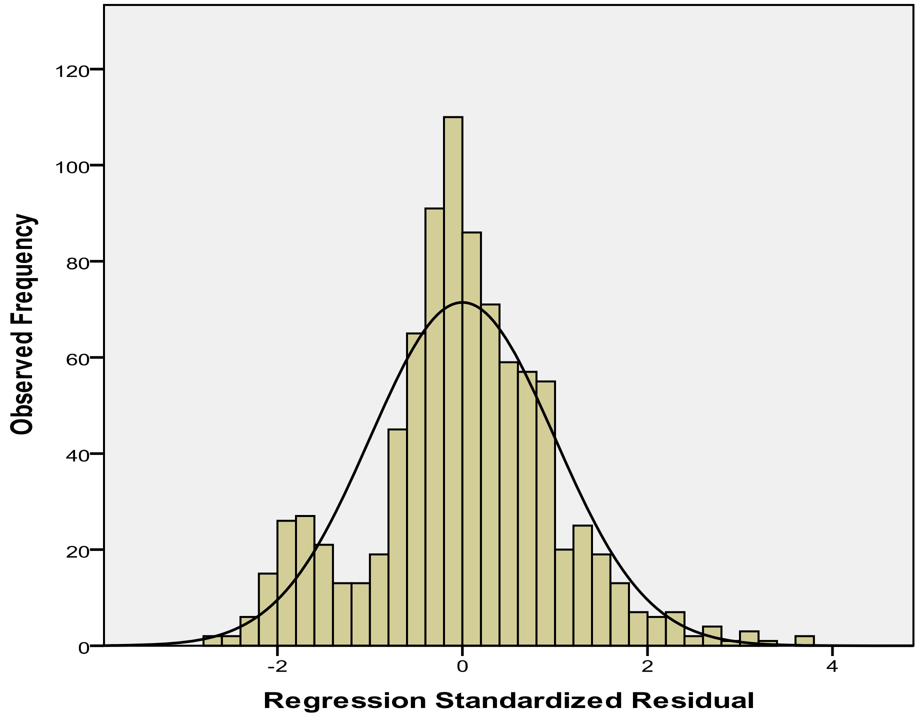


Figure 61: High-Volume Interstate Residual Histogram

According to Figure 61, no gross violations dispute the statement that the residuals are approximately normally distributed. A mean residual of approximately zero presented in Table 53 further suggests the distribution of the disturbances is normal about zero, fulfilling the requirements of the normally distributed disturbances assumption.

Table 53: Residual Descriptive Statistics

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Predicted Value	3.7366	21.9810	11.4468	4.6958
Residual	-12.2787	16.8378	.0000	4.4685

The next assumption requires that the residuals not be correlated. Serial (time) correlation involves residuals that are correlated across time because of the daily pattern that are usually involved with traffic counts throughout the day. It was anticipated that an issue with serial correlation may arise in analysis because this data consists of traffic counts taken every hour over a specific duration of time. This can be determined informally by examining a plot of residuals vs. time. However, a formal test for autocorrelation is the Durbin-Watson statistic, which provides a quantitative measure of the autocorrelation of the data. A value of two indicates no autocorrelation, a value between zero and two may indicate positive autocorrelation, while a value between two and four may indicate negative autocorrelation. The value given is compared to a set of values for critical Durbin-Watson statistics based on the number of observations and the number of independent variables. The limiting value of this statistic is called dL and represents the lower limit of the Durbin-Watson statistic while assuming no autocorrelation is present. The value of dL for large sample sizes and six independent variables is 1.623. The results of this model indicate a value of 0.618, suggesting the data is serially correlated.

Table 54: Collinearity Statistics

Variable	**Tolerance**	**VIF**
Lunch Peak	1.000	1.000
Nearest Upstream Distance	0.796	1.256
Nearest Downstream Distance	0.729	1.372
Facility Condition Rating	0.675	1.481
Mainline % Trucks	0.941	1.063

Table 55: Collinearity Diagnostics

Dimension	**Eigenvalue**	**Condition Index**
1	4.906	1.000
2	0.526	3.054
3	0.292	4.099
4	0.208	4.858
5	0.051	9.804
6	0.017	17.220

The variance influence factor (VIF) is an indicator of multicollinearity between two or more independent variables and is equal to the reciprocal of the tolerance value. VIF values above two indicate a potential problem due to inflation the standard error of the regression coefficients. According to Table 54, the VIF for all variables in this model are below two, suggesting the independent variables used in the model do not suffer from multicollinearity.

Eigenvalues represent another metric to measure collinearity. Values close to zero indicate highly-correlated predictors, suggesting small changes in data values may lead to large changes in coefficient estimates. The condition index is computed as the square root of the ratio of the largest eigenvalue (associated with the intercept) to each eigenvalue. A value greater than 15 indicates possible problem while a value greater than 30 indicates a serious problem. The eigenvalues and associated condition indices presented in Table 55 suggest there may be a problem due to the last condition index (17.220).

The next assumption (commonly known as the exogeneity assumption) states all independent variables must vary autonomously or independent of the other variables in the model. This does not mean the independent variables cannot covary, but one independent variable cannot be dependent on another variable. As an example, the downstream distance and the upstream distance may covary (if one distance increases the other may increase or decrease); however neither of these distances is directly dependent on the other. Therefore, it is anticipated that this assumption will not be violated in this analysis. Table 56 presents the correlations between variables. No value is large enough to cause concern, suggesting exogeneity is not violated.

Table 56: Coefficient Correlations

	% Trucks	Lunch Peak	Nearest Upstream	Nearest Downstream	Condition
% Trucks	1.000	0.017	-0.120	-0.183	0.013
Lunch Peak	0.017	1.000	0.002	-0.001	0.007
Upstream	-0.120	0.002	1.000	0.310	0.423
Downstream	-0.183	-0.001	0.310	1.000	0.476
Condition	0.013	0.007	0.423	0.476	1.000

The final assumption requires that the residuals be homoscedastic, or constant. Homoscedasticity is checked informally using a plot of the predicted values vs. the residuals. In this plot, the number and distance of the points from zero should be approximately equal. Referring back to Figure 55, the range of the residuals does increase at greater values of the predicted value relative to the lower values of predicted value, suggesting a potential problem with heteroscedasity.

Low-Volume Interstate Model Diagnostics: Regression analysis of the data for this category yielded a model with the lowest R-square value (0.320) amongst the models developed. The low significance of the F-statistic presented in Table 57 suggests the model provides a better predictor than using average.

Table 57: Low-Volume Interstate Model Summary

R^2	Adjusted R^2	Std. Error of Estimate	F	Significance
0.320	0.315	3.91104	63.051	<0.001

Table 58: Model Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	Coefficient	**Standard Error**		**t-statistic**	**Significance**
Intercept	-112.755	20.649		-5.461	0.000
Lunch Peak	1.578	0.240	0.166	6.568	0.000
Nearest Upstream	1.186	0.314	2.988	3.770	0.000
$(\text{Nearest Upstream})^2$	-0.014	0.004	-2.180	-3.443	0.001
Nearest Downstream	1.208	0.215	3.337	5.629	0.000
$(\text{Nearest Downstream})^2$	-0.015	0.003	-3.739	-5.896	0.000
Condition	29.462	4.190	1.783	7.031	0.000
% Trucks	3.870	0.546	4.924	7.081	0.000
$(\text{\% Trucks})^2$	-0.118	0.016	-6.024	-7.435	0.000

According to Table 58, all predictors are significant under the specified 95% confidence level. The values of the standardized coefficients suggest the mainline % trucks has the largest effect on rest area usage for the low-volume interstate category, which was also the case for the high-volume interstate category. Diagnostic analysis was also performed on the low-volume interstate model similar to the high-volume interstate model.

Next the linearity assumption will be checked similar to the previous analysis. Because a curvilinear relationship is not apparent between the residual and the predicted value (Figure 62), it is believed that the assumption of a linear relationship between the variables is linear is valid. The relationship between the residual and the nearest upstream distance (Figure 63) may exhibit a curvilinear trend, especially because of the

Custer westbound site with an upstream distance of approximately 38 miles. A similar trend exists between the residual and the nearest downstream distance (Figure 64). This is strongly due to one particular site (Custer westbound) which exhibits essentially all negative residuals. No curvilinear trend between the mainline % trucks and the residuals is present, suggesting linear relationship (Figure 65). For the lunch peak variable, no trend can be represented because the variable is binary (Figure 66).

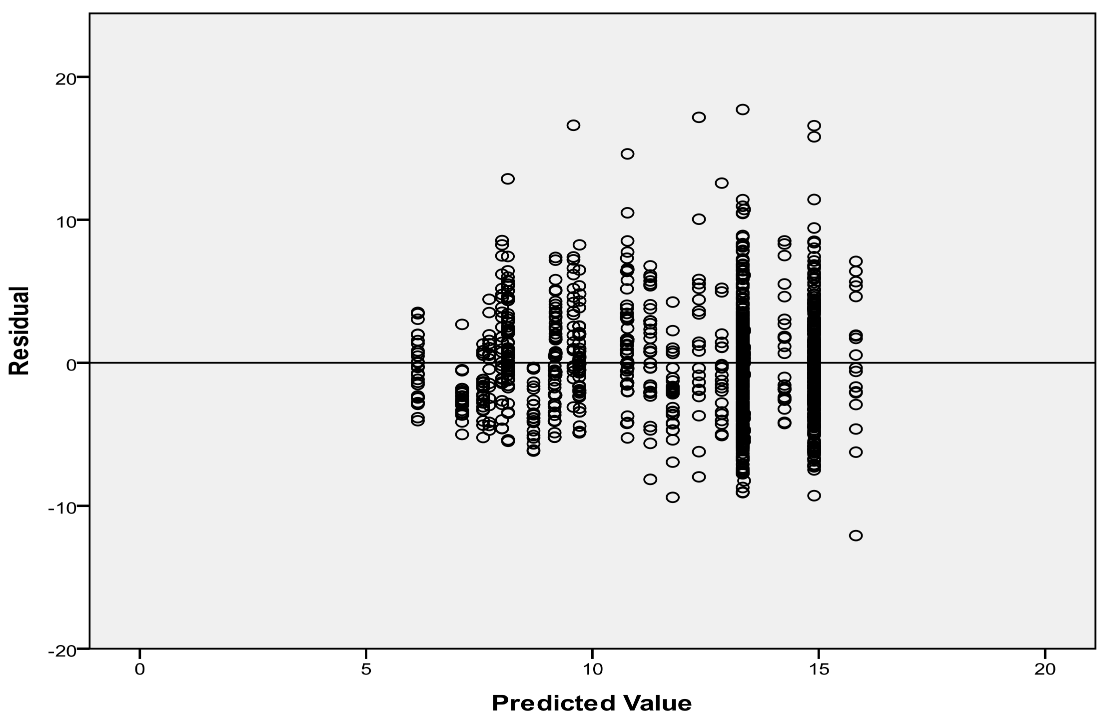


Figure 62: Low-Volume Interstate: Residual vs. Predicted Value

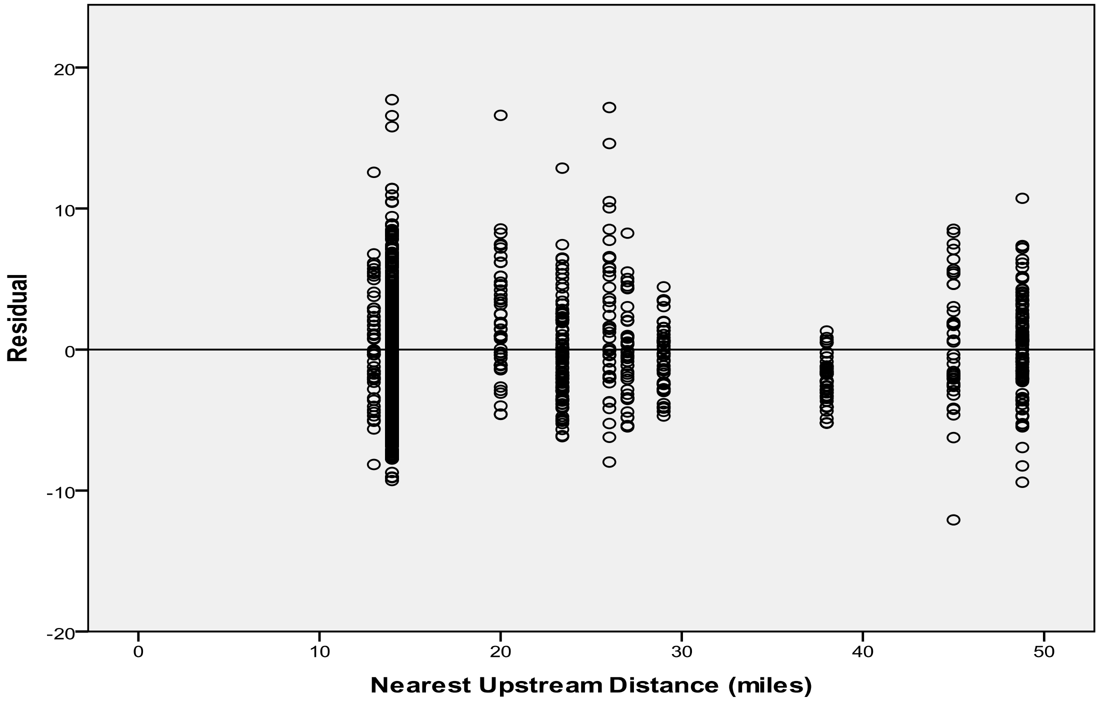


Figure 63: Residual vs. Nearest Upstream Distance

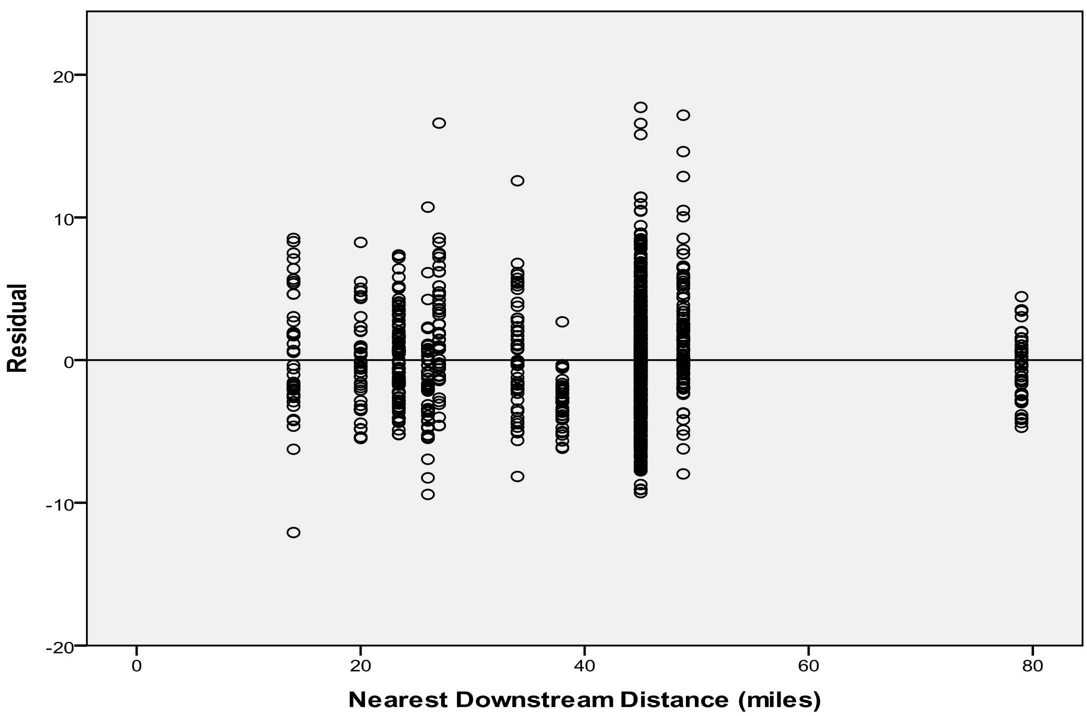


Figure 64: Residual vs. Nearest Downstream Distance

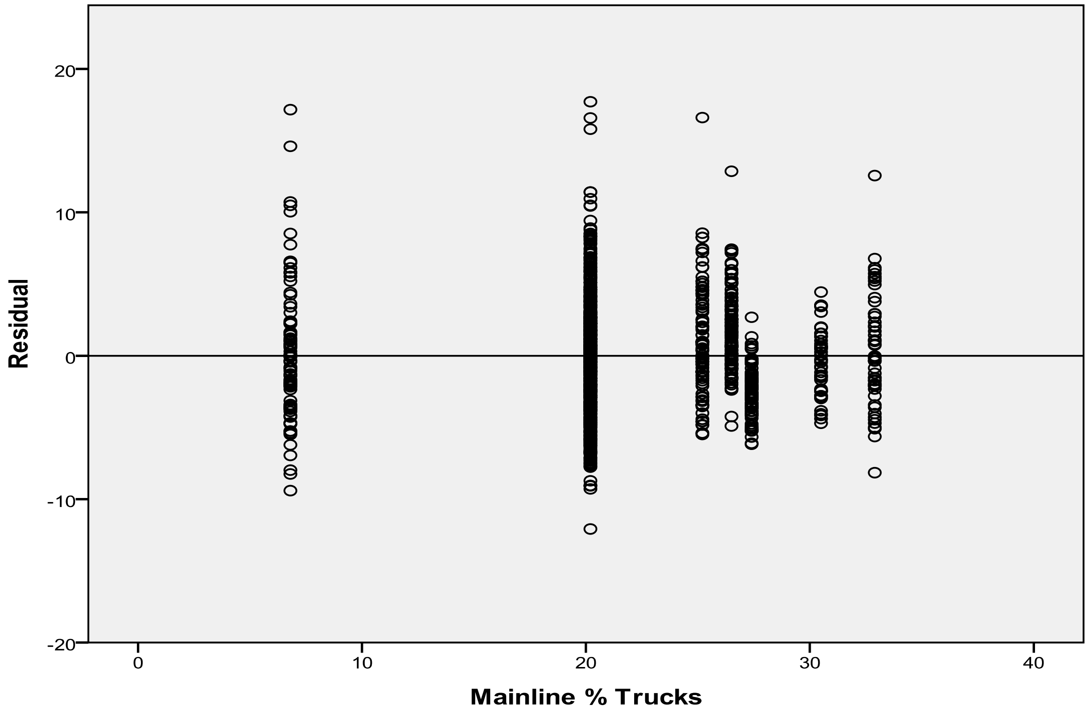


Figure 65: Residual vs. Mainline % Trucks

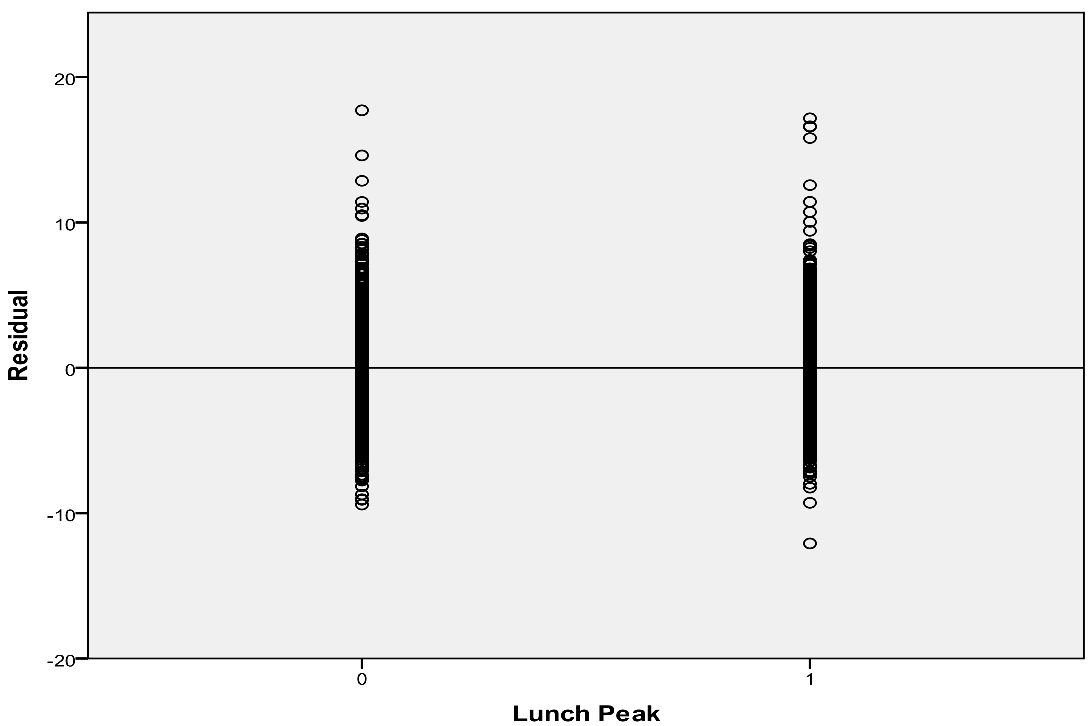


Figure 66: Residual vs. Lunch Peak

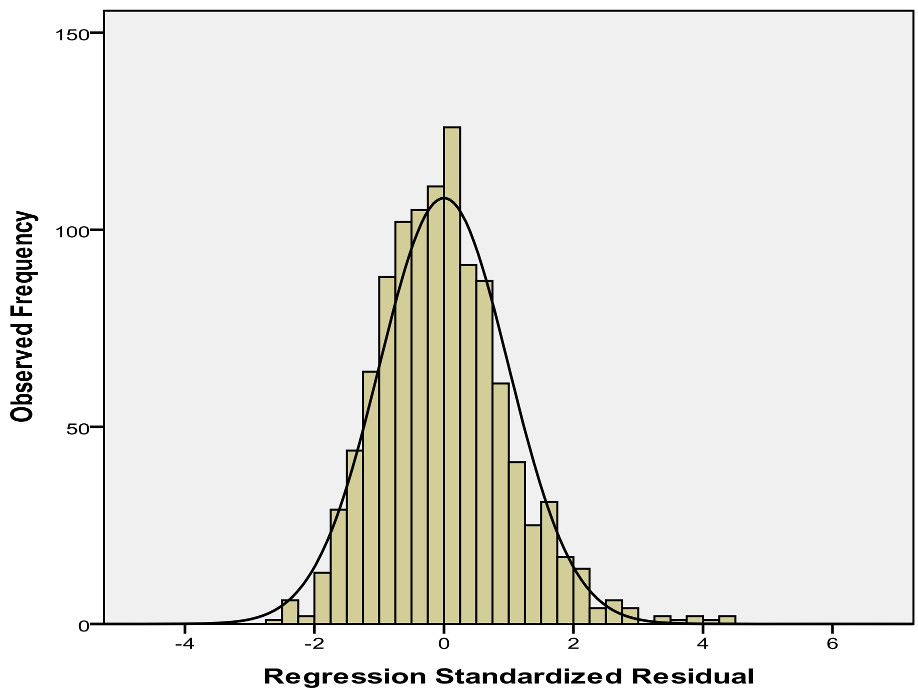


Figure 67: Low-Volume Interstate Residual Histogram

Table 59: Residual and Predicted Value Descriptive Statistics

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Predicted Value	6.1406	15.8205	11.9950	2.6741
Residual	-12.0822	17.7152	.0000	3.8965

To check the normally distributed disturbances assumption, examine Figure 67. Based on a brief examination, the residuals appear approximately normally distributed. Table 59 also suggests the mean of the residuals is approximately zero, fulfilling another requirement of linear regression.

To test for serial correlation, the Durbin-Watson test was employed. Comparing the Durbin-Watson statistic of 1.771 to the limiting value for 8 independent variables of

1.757, this test suggests the disturbances are not serially correlated unlike the high-volume interstate category.

The low tolerances and high VIF's presented in Table 60 and Table 61 suggest the independent variables are highly collinear. This follows logic because three variables are square transformations of other independent variables.

According to Table 62, several independent variables are highly correlated, suggesting some of the variables may not be required for the model. However, it is believed to be reasonable to have the transformed variables highly correlated with their original counterparts.

Table 60: Collinearity Statistics

Variable	**Tolerance**	**VIF**
Lunch Peak	0.999	1.001
Upstream	0.001	989.272
$Upstream^2$	0.002	631.511
Downstream	0.002	553.694
$Downstream^2$	0.002	633.513
Condition	0.010	101.338
% Trucks	0.001	761.756
% $Trucks^2$	0.001	1034.200

Table 61: Collinearity Diagnostics

Dimension	**Eigenvalue**	**Condition Index**
1	7.231	1.000
2	0.873	2.877
3	0.548	3.634
4	0.248	5.398
5	0.086	9.194
6	0.009	28.516
7	0.004	44.212
8	0.002	58.422
9	1.544E-5	684.304

Table 62: Coefficient Correlations

Variable	**% Trucks^2**	**Lunch Peak**	**Upstream**	**Downstream^2**
% Trucks^2	1.000	0.008	-0.969	0.963
Lunch Peak	0.008	1.000	-0.011	0.011
Upstream	-0.969	-0.011	1.000	-0.965
Downstream^2	0.963	0.011	-0.965	1.000
Condition	-0.989	-0.007	0.969	-0.969
Downstream	-0.954	-0.011	0.956	-0.998
Upstream^2	0.955	0.011	-0.997	0.945
% Trucks	-0.999	-0.008	0.966	-0.964

Table 62 Continued

Variable	**Condition**	**Downstream**	**Upstream^2**	**% Trucks**
% Trucks^2	-0.989	-0.954	0.955	-0.999
Lunch Peak	-0.007	-0.011	0.011	-0.008
Upstream	0.969	0.956	-0.997	0.966
Downstream^2	-0.969	-0.998	0.945	-0.964
Condition	1.000	0.958	-0.957	0.984
Downstream	0.958	1.000	-0.934	0.956
Upstream^2	-0.957	-0.934	1.000	-0.950
% Trucks	0.984	0.956	-0.950	1.000

Checking the homoscedastic residuals assumption, refer back to Figure 62. While the variation in disturbances is lower for the lower values of predicted value, it is believed no linear pattern exists because residuals do not increase or decrease linearly with an increase in predicted value, suggesting no violation in the homoscedastic residual assumption.

High-Volume Arterial Model Diagnostics: Descriptive statistics of the model developed for the high-volume arterial category are presented in Table 63 below. This model provided the largest R-square value (0.640) of all models. The large value of the

F-statistic with the associated small significance suggests the model would make a better predictor of rest area usage on high-volume arterials relative to using the mean.

Table 63: High-Volume Arterial Model Summary

R^2	Adjusted R^2	Standard Error of Estimate	F	Significance
0.640	0.638	3.51317	259.014	<0.001

Table 64: Model Coefficients

Variable	Unstandardized Coefficients		Standardized Coefficients		
	Coefficient	Standard Error	Beta	t	Significance
Intercept	-7.448	1.928		-3.862	<0.001
Lunch Peak	1.256	0.293	0.107	4.286	<0.001
Nearest Upstream Area	0.178	0.011	0.811	16.608	<0.001
Nearest Downstream City	0.079	0.024	0.198	3.338	0.001
Weigh Station	6.219	0.677	0.325	9.183	<0.001

The low values of the significance of all variables suggest all variables are important in the model. Examining the standardized coefficients presented in Table 64, the distance to the nearest upstream area appears to be the most significant variable in estimating rest area usage on high-volume arterials. Diagnostic analysis was performed on this model similar to previous models.

Checking the linearity assumption, examination of Figure 68 suggests the possibility of a curvilinear relationship between the residual and the predicted value. This may suggest at least one of the independent variables may need to be transformed in order to obtain a linear relationship between all variables. The plots of the independent variables against the residuals will be examined to identify the variable that needs changing.

Examination of Figure 69 suggests no curvilinear trend between the model residuals and the upstream area variable. Examination of Figure 70 also does not have a curvilinear trend, suggesting the relationship between the residual and the distance to the nearest downstream city is linear. The weigh station and lunch peak variables are binary (0 or 1), therefore no curvilinear trend can be taken from these (Figure 71 and Figure 72). Based on this analysis, it is believed that the linearity assumption is not violated.

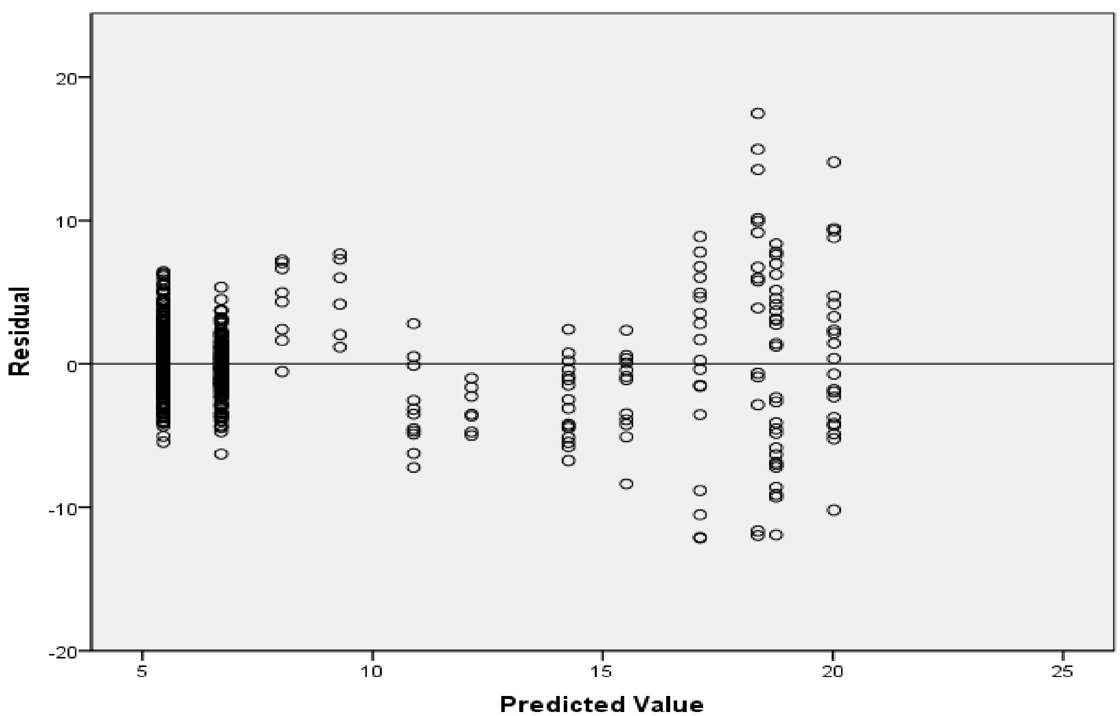


Figure 68: High-Volume Arterial: Residual vs. Predicted Value

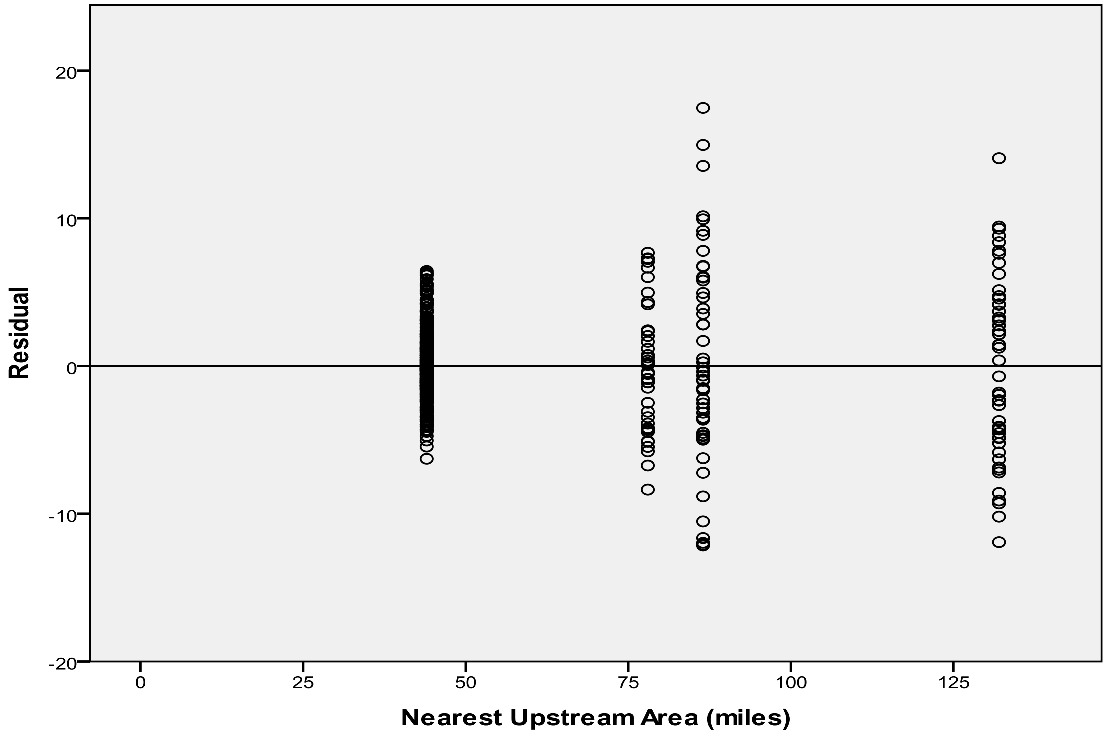


Figure 69: Residual vs. Nearest Upstream Area

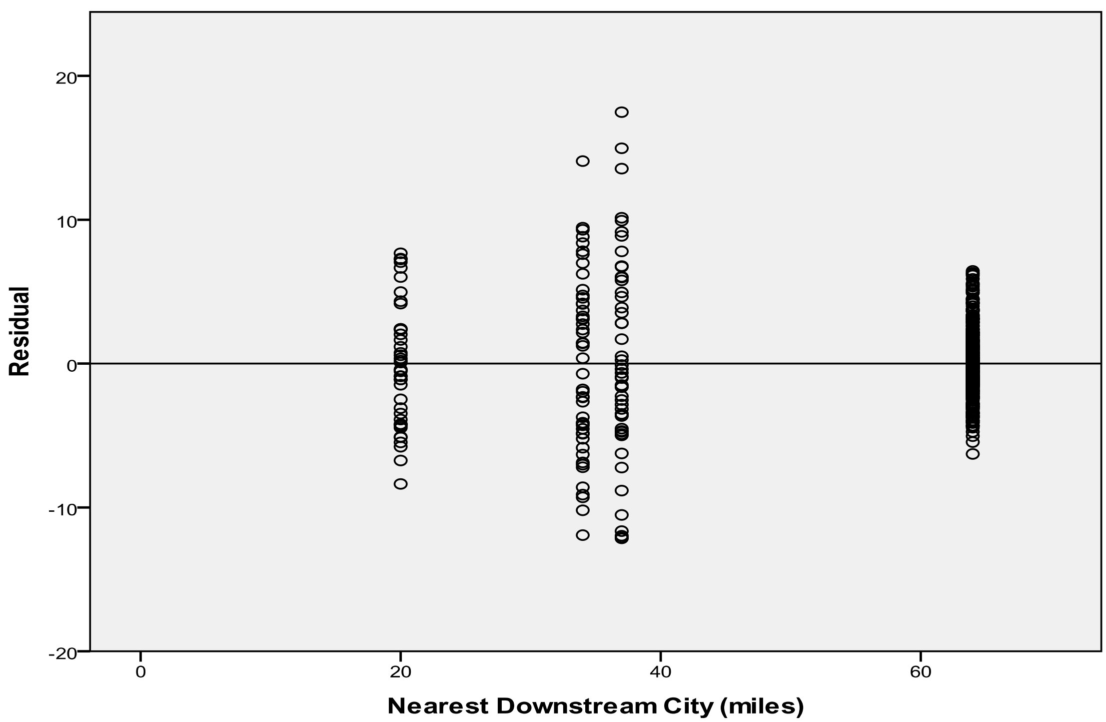


Figure 70: Residual vs. Nearest Downstream City

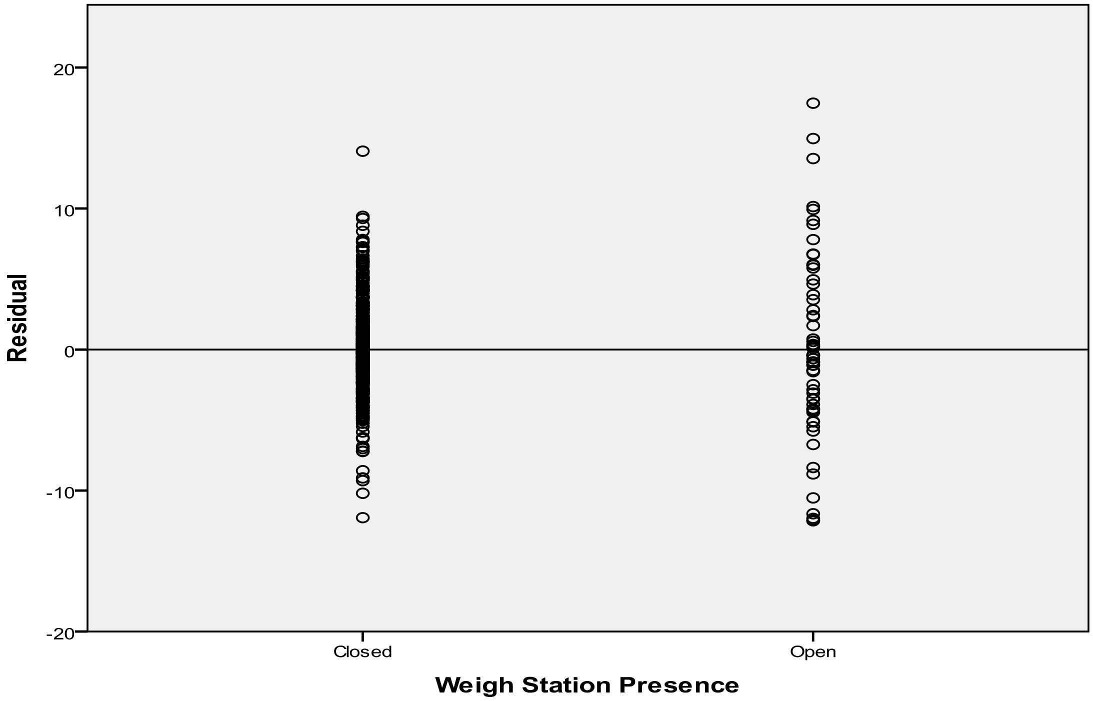


Figure 71: Residual vs. Weigh Station Presence

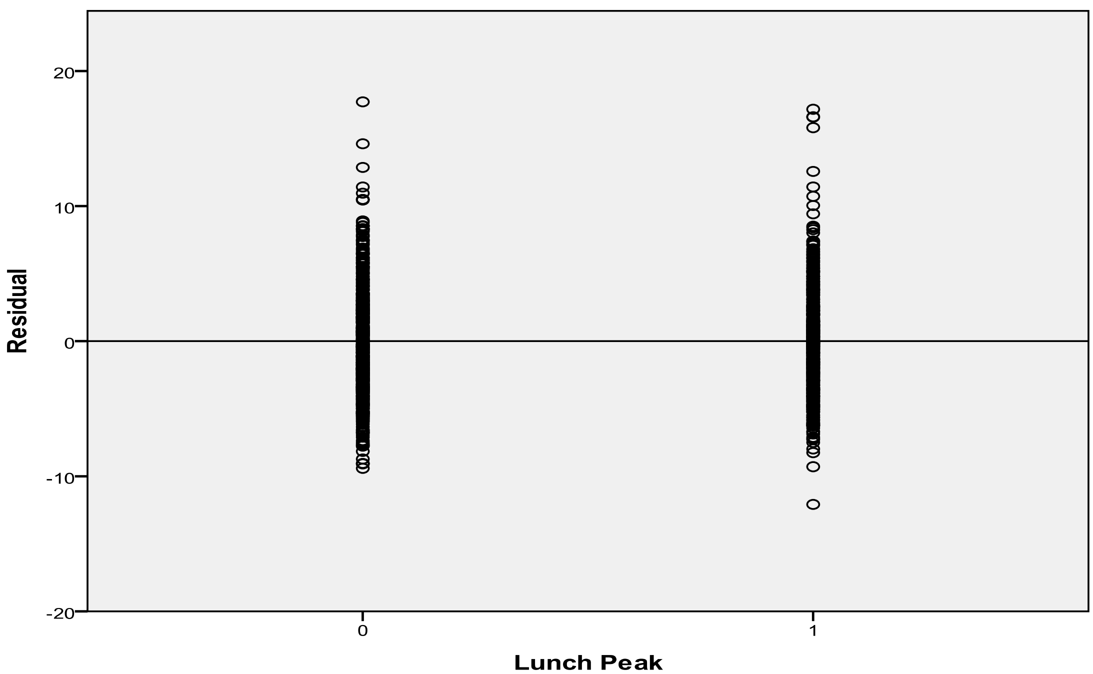


Figure 72: Residual vs. Lunch Peak

Next the normally distributed residuals assumption will be checked. Based on the residual histogram presented in Figure 73, it appears the residuals approximate a normal distribution. Summary statistics provided in Table 65 suggest the mean of the residuals is very close to zero. Therefore, it is believed the normally distributed disturbances assumption is not violated for this model.

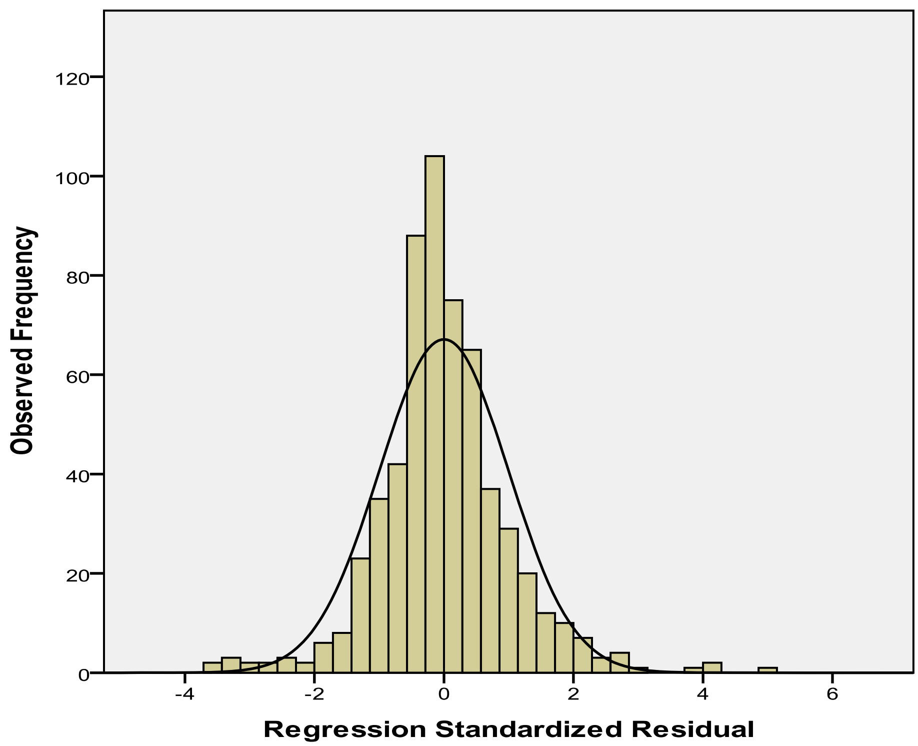


Figure 73: High-Volume Arterial Residual Histogram

Table 65: Residual Statistics

	Minimum	Maximum	Mean	Std. Deviation
Predicted Value	5.4533	20.0221	8.4054	4.67135
Residual	-12.15123	17.47303	.00000	3.50116

To check for serial correlation, the Durbin-Watson test was conducted similar to previous models. Regression produced a Durbin-Watson statistic of 1.362. Because the lower limit of the Durbin-Watson statistic for 4 variables is 1.633, autocorrelation is present within the data set. Time-series analysis was attempted with little success.

In checking the exogeneity assumption, all tolerance and VIF values in Table 66 suggest collinearity between independent variables is not present for these models. However, the eigenvalues and associated condition indices presented in Table 67 suggest a problem is present due to the final condition index greater than 30. The coefficient correlations presented in Table 68 suggest a strong correlation between the downstream city and upstream rest area variables.

Table 66: Collinearity Diagnostics

Variable	**Tolerance**	**VIF**
Intercept		
Lunch Peak	1.000	1.000
Nearest Upstream Area	0.259	3.859
Nearest Downstream City	0.176	5.680
Weigh Station	0.492	2.032

Table 67: More Collinearity Diagnostics

Dimension	**Eigenvalue**	**Condition Index**
1	3.426	1.000
2	0.918	1.932
3	0.484	2.661
4	0.168	4.516
5	0.004	31.125

Table 68: Coefficient Correlations

	Weigh Station	**Lunch Peak**	**Upstream Rest Area**	**Downstream City**
Weigh Station	1.000	-0.013	0.437	0.671
Lunch Peak	-0.013	1.000	-0.006	-0.008
Upstream Rest Area	0.437	-0.006	1.000	0.843
Downstream City	0.671	-0.008	0.843	1.000

To check the homoscedastic residuals assumption, the plot of residuals vs. predicted values will be examined again (Figure 68). Based on this plot, there appears to be a problem with heteroscedasity because the range of the residuals increases as the predicted value increases.

Low-Volume Arterial Model Diagnostics: Table 69 presents the descriptive statistics of the model developed for the low-volume arterial category. An R square value of 0.516 suggests approximately 51% of the variation in the data is explained by the model. The significance of the F-statistic being less than 0.001 suggests the model provides a better prediction of rest area usage on low-volume arterials than using the average.

Table 69: Low-Volume Arterial Model Summary

R^2	**Adjusted R^2**	**Std. Error of the Estimate**	**F**	**Sig.**
0.516	0.512	6.95564	133.634	<0.001

According to Table 70, all variables are significant with 95% confidence. Also, all significance values are less than 0.001 with the exception of the lunch peak variable, with a significance of 0.014. Examination of the standardized coefficients suggests the nearest upstream distance has the most significant impact on rest area usage.

Table 70: Model Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	**Std. Error**	**Beta**	**t**	**Significance**
Intercept	-19.308	1.984	N/A	-9.730	<0.001
Lunch Peak	1.161	.472	0.058	2.460	0.014
Nearest Upstream	.980	.059	2.180	16.495	<0.001
(Nearest Upstream)^2	-.010	.001	-2.680	-18.980	<0.001
Nearest Downstream	.241	.045	1.089	5.413	<0.001
(Nearest Downstream)^2	-.002	.000	-1.304	-5.861	<0.001
Weigh Station Operation	22.762	2.088	0.264	10.902	<0.001
Mainline % Trucks	.624	.052	0.610	11.922	<0.001

Regression diagnostics analysis was performed on this model using the same method discussed for previous category models, starting with the linearity assumption. Looking at Figure 74, it appears there may be a curvilinear relationship between the residual and the predicted value (second order polynomial or U-shape). This may be due to the relationship between the residual and the nearest upstream distance, as Figure 75 appears to exhibit several waves. However, this was addressed by adding a square term for the upstream distance variable to the model. The same phenomenon also occurs with the nearest downstream distance (Figure 76). Similar to the nearest upstream distance variable, this was addressed by adding a square term for the downstream distance variable. The weigh station operation variable is binary, therefore linearity cannot be checked (Figure 77). The plot of mainline % trucks in Figure 78 also appears to exhibit a distribution which has a curvilinear shape, suggesting a non-linear relationship.

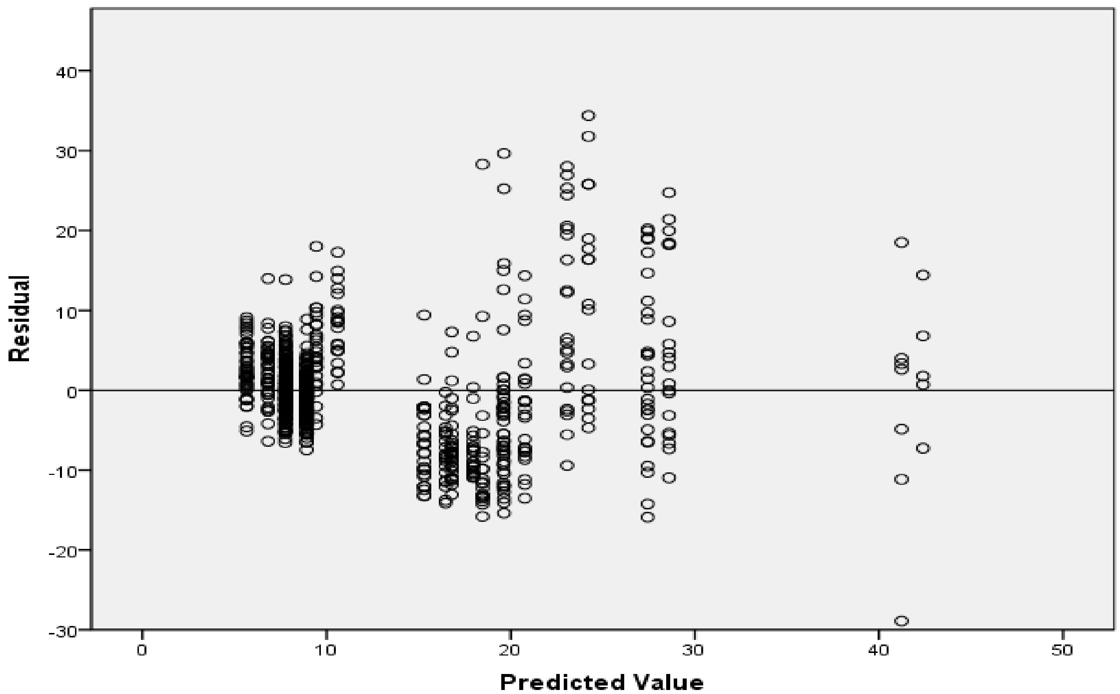


Figure 74: Low-Volume Arterial: Residual vs. Predicted Value

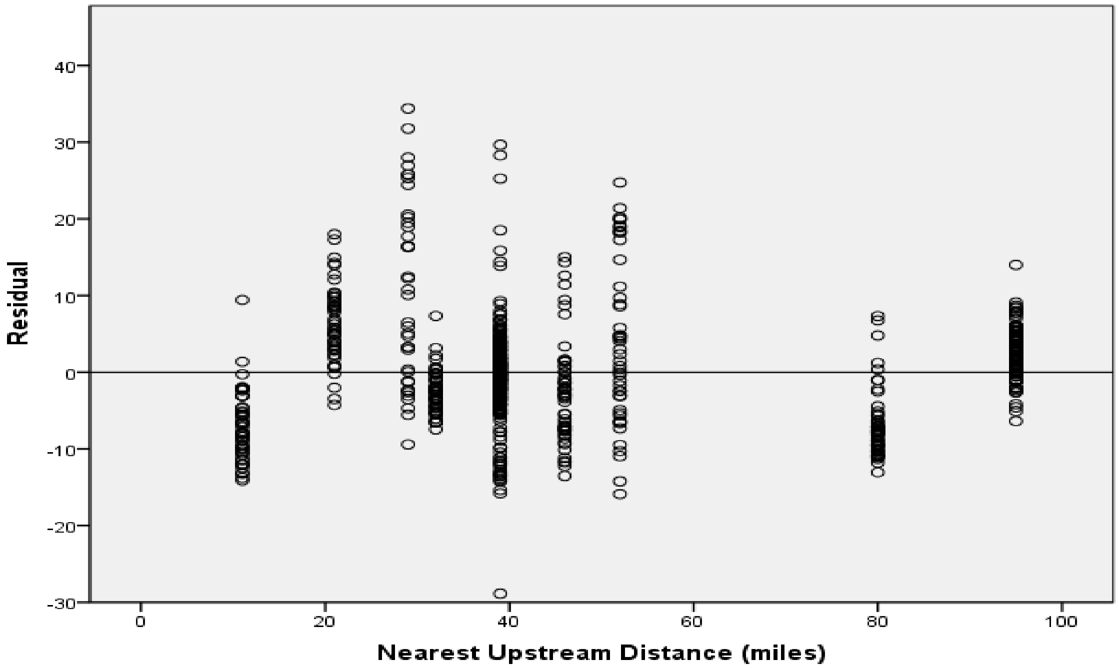


Figure 75: Residual vs. Nearest Upstream Distance

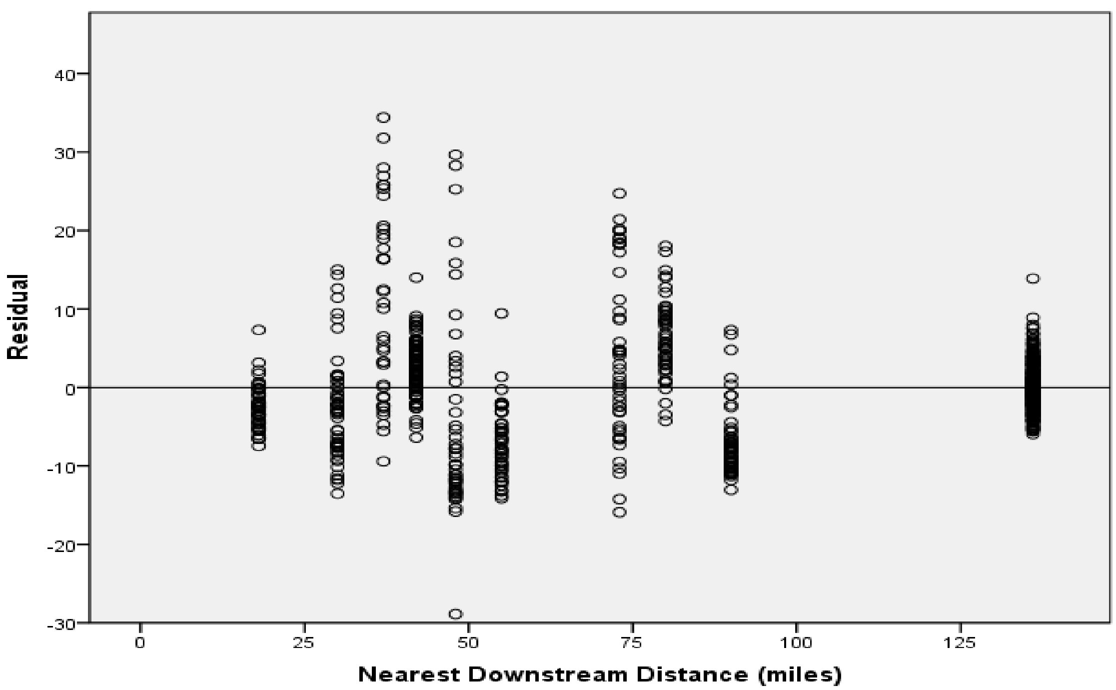


Figure 76: Residual vs. Nearest Downstream Distance

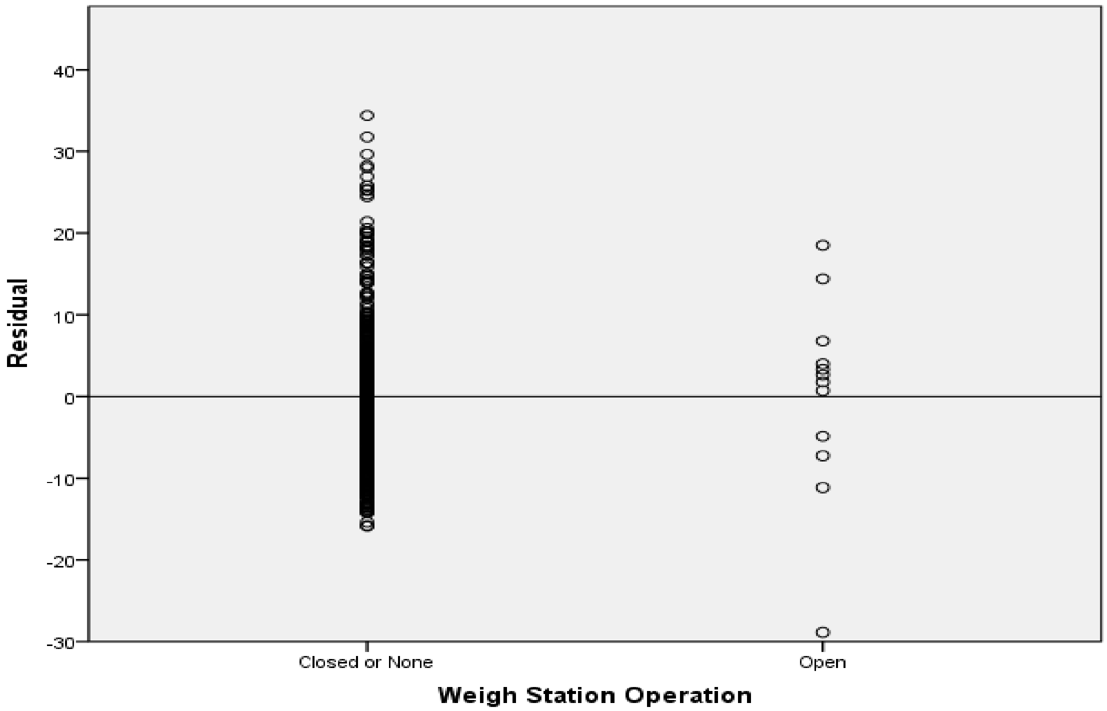


Figure 77: Residual vs. Weigh Station Operation

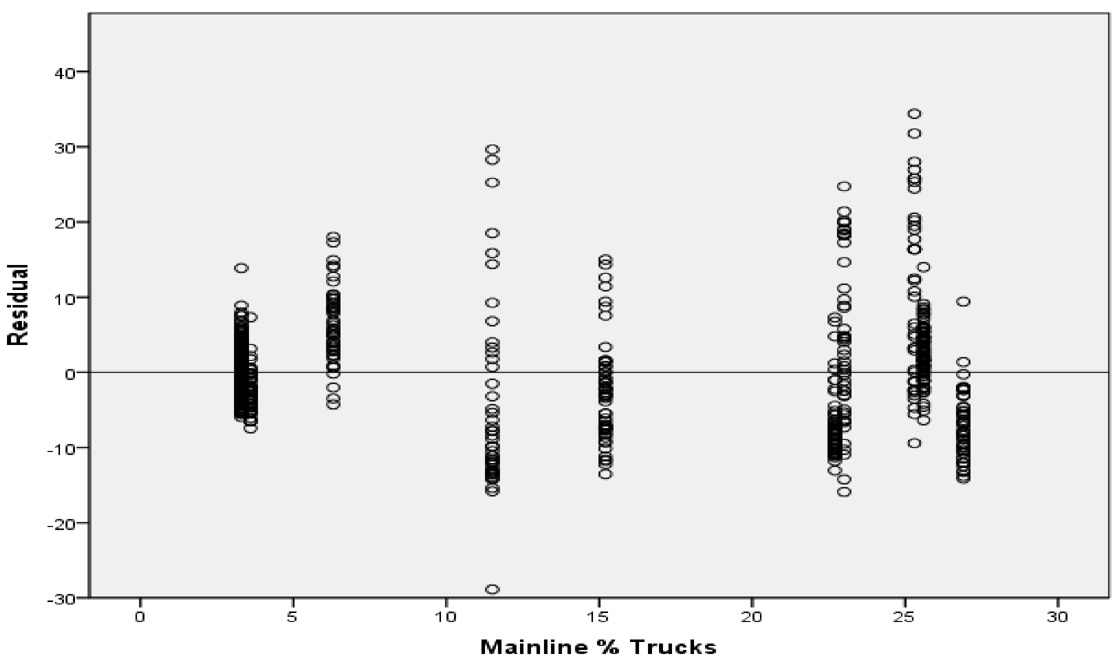


Figure 78: Residual vs. Mainline % Trucks

Next, the normally distributed residuals assumption was checked. According to Figure 79, the residuals are acceptably close to being considered normally distributed. Also looking at Table 71, the mean of the residuals is approximately zero. This discussion leads to the conclusion that the residuals do not violate the normally distributed about zero assumption.

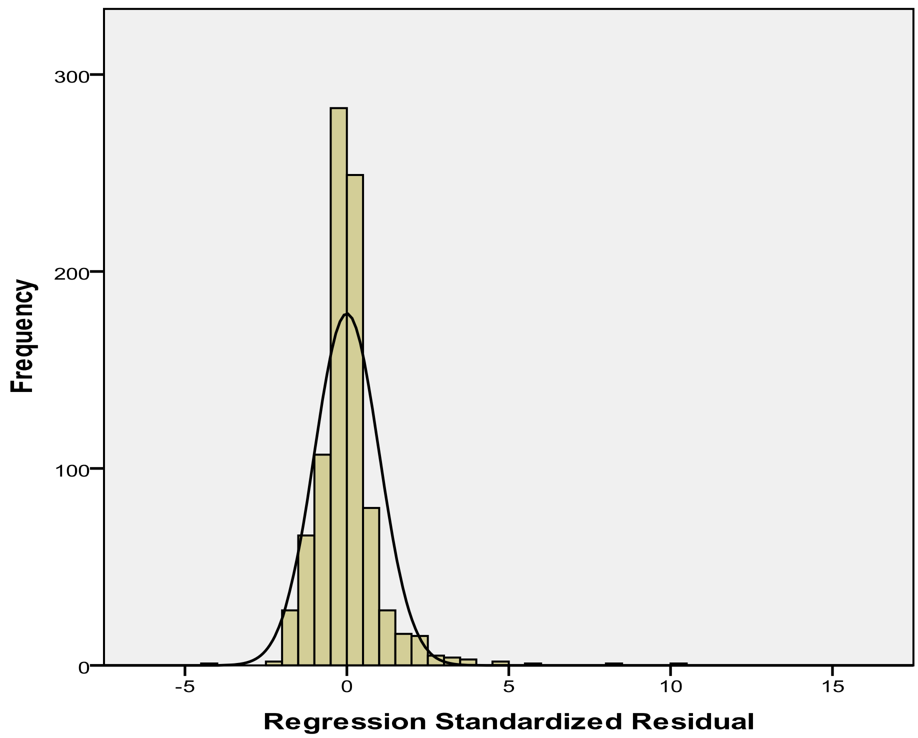


Figure 79: Low-Volume Arterial Residual Histogram

Table 71: Predicted Value and Residual Descriptive Statistics

	Minimum	Maximum	Mean	Std. Deviation
Predicted Value	5.6579	42.3908	12.4202	7.14706
Residual	-28.88391	34.39835	.00000	6.92810

Serial correlation was checked using the Durbin-Watson test similar to the previous analyses. Because the Durbin-Watson statistic of 1.016 resulting from the model is significantly less than the critical value of 1.875, this suggests the data is serially correlated similar to the high-volume interstate and high-volume arterial categories.

The tolerance and VIF value presented in Table 72 suggest a problem with multicollinearity may exist, violating the exogeneity assumption. This statement is supported by the eigenvalues and associated condition indices provided in Table 73. The multicollinearity could be explained by the transformations done to the upstream and downstream distance variables previously discussed. This hypothesis is confirmed by Table 74 which shows that the upstream and downstream distances are highly correlated with the associated transformations.

Table 72: Collinearity Statistics

	Collinearity Statistics	
	Tolerance	**VIF**
Lunch Peak	1.000	1.000
Nearest Upstream Distance	.032	31.703
(Nearest Upstream Distance)^2	.028	36.169
Nearest Downstream Distance	.014	73.398
(Nearest Downstream Distance)^2	.011	89.747
Weigh Station Operation	.938	1.067
Mainline % Trucks	.210	4.751

Table 73: Collinearity Diagnostics

Dimension	Eigenvalue	Condition Index
1	5.070	1.000
2	1.098	2.149
3	.986	2.267
4	.553	3.028
5	.240	4.601
6	.048	10.265
7	.004	36.945
8	.002	56.596

Table 74: Coefficient Correlations

	Mainline % Trucks	Lunch Peak	Weigh Station
Mainline % Trucks	1.000	.003	.135
Lunch Peak	.003	1.000	.003
Weigh Station	.135	.003	1.000
Nearest Upstream Distance	.204	.002	-.110
Nearest Downstream Distance	-.532	.000	-.148
(Nearest Upstream Distance)^2	-.304	-.002	.109
(Nearest Downstream Distance)^2	.614	.001	.176

Table 74 Continued

Nearest Upstream Distance	Nearest Downstream Distance	(Nearest Upstream Distance)^2	(Nearest Downstream Distance)^2
.204	-.532	-.304	.614
.002	.000	-.002	.001
-.110	-.148	.109	.176
1.000	.087	-.978	-.107
.087	1.000	-.052	-.986
-.978	-.052	1.000	.067
-.107	-.986	.067	1.000

An informal check for heteroscedascity was performed similar to previous analyses. Referring back to the plot of residuals vs. predicted values (Figure 74), a trend is present in which the range of the disturbances increases as the predicted value increases, suggesting heteroscedastic residuals.

Patron/Door Count Correlation

Patron count data is a necessary input in determining wastewater treatment system capacity as well as the required number of restroom stalls at a rest area facility. Of interest to this research were figures related to water usage, and, consequently, wastewater generated per patron at Montana rest areas. Door counts of rest area patrons entering and exiting the rest room at each rest area examined in this research were collected by MDT, as previously discussed. However, the counts collected by the devices employed at restroom doorways required manual verification to determine the relationship between the actual number of patrons using the rest area and the door counts recorded using the automated counters. The reason behind this verification is the assumption that, sometimes, more than one person may enter or exit the rest area during the same door opening (especially when patrons come in groups). In order to verify this assumption, field data was collected at four rest area sites as discussed in Chapter 3. Using this data, a correlation factor between the number of patrons using the rest area facility and the door counts being recorded by MDT could be determined. It was anticipated that the factor would be close to two, suggesting the majority of patrons enter and exit the facility individually. As the results of Table 75 indicate, this proved to be correct, as the correlation factor at each of the sites examined was approximately equal to

2. As a result, dividing the counts recorded by the automatic door counters by two would provide a good approximation of the number of patrons using the rest area facilities and was used in the analyses discussed in the next section. It is believed that the slight portion of these factors above 2.0 is attributed to multiple patrons (i.e. a parent and child) entering and/or exiting a rest area building simultaneously.

Table 75: Patron/Door Count Correlation Factors

Site	# of entries/exits	# of patrons	Factor
Anaconda	230	112	2.05
Bozeman	498	245	2.03
Divide southbound	155	77	2.01
Greycliff eastbound	197	98	2.01

Patron/Vehicle Correlation Analysis

Many aspects of rest area design rely directly or indirectly on vehicle counts. One indirect use of vehicle count data is a determination of the number of patrons using the rest area per vehicle. Such information may be employed in the sizing of rest area facilities, from the size of the overall building(s) to specifics such as restroom fixtures. Therefore, the relationship between the number of vehicles and the number of patrons observed entering restrooms was established by this work.

Data from the manual site observations collected and used in the patron/door count correlation, along with the corresponding rest area traffic data collected concurrently were used to determine the rate of patrons per vehicle using a rest area. The calculated rate was simply the number of patrons using the rest area based on the number of vehicles entering the rest area. For this analysis, traffic data were only available from the two control stations at the time of the patron observation data collection. These sites were Divide southbound and Greycliff eastbound. The approximate patrons to vehicles rates for these two sites are provided in Table 76.

Table 76: Patrons per Vehicle at Divide and Greycliff Rest Areas

Site	# of patrons	# of vehicles	Patrons-to-Vehicles Rate
Divide southbound	77	53	1.46
Greycliff eastbound	98	73	1.35

The vehicle occupancy rate at the Divide southbound site was approximately 1.46 patrons per vehicle, while at the Greycliff eastbound site this rate was approximately 1.35 patrons per vehicle. Due to the lack of corresponding traffic data at the two sites on non-interstate arterials, a rate for this facility type has not been presented. However, using available traffic and door count data from the control stations at Emigrant and Bridger, the average patrons-to-vehicles rates at these sites could be calculated. Results found those rates to be 1.78 and 1.44, at Emigrant and Bridger, respectively. The value for Emigrant was expected to be slightly higher due to the recreational nature of the mainline facility (US-89), as it services the Gardiner entrance to Yellowstone National Park.

Water Meter Data Processing and Analysis

Based on the correlation analysis results, the door counts provided by MDT were divided by two to obtain the number of patrons, assuming that the majority of patrons enter and exit the rest area individually and that each person enters and exits the facility once. With a figure of daily patrons visiting each rest area, a calculation of the amount of water used and wastewater generated per patron could be made. This was accomplished by dividing a specific day's water meter reading by the number of patrons at the rest area for that day.

With a data collection effort as extensive in scope and duration as that pursued in this research, counter errors and malfunctions were to be expected. During the course of the analysis, suspect water meter data was observed at the Culbertson, Hardin WB, Mosby, Troy and Vandalia rest areas. In examining general data trends, it became evident that water usage at these rest areas was abnormally small or large in values and their inclusion may introduce a bias into the results of water usage analysis. Consequently, the data collected at these sites were excluded from the analysis.

In other cases, data collected at various rest areas indicated that a short term counter or meter malfunctions had occurred or there had been an error in recording and/or reporting the readings. Regardless of the error, such data points needed to be identified and addressed in order to ensure they would not affect or skew the overall results and conclusions related to water use and wastewater generated. To identify potential errors/outliers, a range of three standard deviations above and below the average for each site was designated as the acceptable range of values to employ in this work. Any values outside of this range were deemed outliers and removed from further analyses. Once the data set had been verified and processed, the requisite descriptive statistics representing water usage and wastewater generated for each rest area category were developed. These descriptive statistics are presented in Table 77.

Table 77: General Statistics for Water Usage per Patron

	Mean (gal/patron)	**Median (gal/patron)**	**Mode (gal/patron)**	**Standard Deviation (gal/patron)**
Interstate	1.45	1.24	2	0.96
Arterial	1.46	1.25	1	0.78
Overall	1.45	1.24	2	0.93

As the table indicates, the overall average water usage per patron at all rest areas collectively was approximately 1.45 gallons per patron, with a standard deviation of 0.93 gallons per patron. Interstate rest areas showed an average of 1.45 gallons per patron, with a standard deviation of 0.96 gallons per patron. Arterial rest areas showed an average of 1.46 gallons per patron with a standard deviation of 0.78 gallons per patron. The standard deviations suggest some variation within the water use data. The percentiles were all found to be similar, with the 85th percentile ranging between 2.36 and 2.53, the 90th percentile ranging between 2.58 and 2.84, and the 95th percentile ranging between 3.00 and 3.32. Differences in use may be directly related to the age and condition of the rest area. Newer rest areas are more likely to employ low flow water fixtures, whereas older facilities that have not been recently reconstructed or remodeled may employ older, high flow fixtures, leading to this difference. Of specific interest to this work is that rest areas on both facility types (interstate and arterial) exhibited similar values of water usage per patron, suggesting facility type may have a negligible impact on water usage/wastewater generation at rest areas.

Based on the results of this analysis, it is evident that water use and wastewater generated at Montana rest areas is generally on the order of 1.5 gallons per patron. Consequently, the figure employed by AASHTO, 3.5 gallons of water used per rest area patron, appears to be a large overestimation when applied to Montana. When one considers that the AASHTO guidance requires a separate addition of the water used by employees in cleaning the rest area, it is clear that a value of over 3.5 gallons, compared to 1.5 gallons in Montana (which includes the water used in cleaning) is a gross overestimation. Of course, the ultimate value employed will need to conform to the requirements set forth by the Montana Department of Environmental Quality (DEQ) for the design of such systems, specifically wastewater treatment systems at sites where city sewer access is not available.

Chapter Summary

This chapter examined rest area data from various perspectives, including usage characterization, development of models to estimate usage and determination of water usage and wastewater generation at Montana rest areas. Rest area usage characterization derived general usage statistics, examined the effect of several variables on rest area usage, and established the time-of-day and day-of-week variation in rest area usage. The major findings of this portion of the work were that the average rest area usage for the different highway categories varied in the range between 8.4 percent and 12.3 percent of mainline traffic entering the rest area. The overall usage average was approximately 10 percent and the overall 85^{th} percentile is around 15 percent of mainline traffic entering the rest area. The high-volume interstate category produced data most consistent with the research hypotheses concerning the effect of rest area condition and percentage of trucks on rest area usage. This was the category that included the highest number of rest areas investigated by this research (18 out of 44). The relatively uniform conditions along interstate highways may explain this observation.

The presence of weigh stations in operation was found to result in a remarkably increased demand at two of the three rest area study sites. No definite reason was found to explain the inconsistency between the sites. While the work identified two peaks during the day for the percentage of mainline traffic using the rest area, vehicular counts at rest areas showed only one peak around mid-day. Therefore, the mid-day period should be considered in the planning and design of rest areas facilities. For three of the four rest area categories investigated (40 out of 44 rest areas), the average rest area usage during the mid-day period varied roughly in the range between 13 percent and 17 percent of mainline traffic.

Following the characterization of rest area usage, linear regression was employed to model rest area usage at high and low-volume interstate sites, as well as high and low-volume arterial rest areas. As a result of this work, the final regression models developed for each category were:

- High-Volume Interstate:
    - $Y = -18.170 + 1.495 * \text{(lunch peak)} + 0.096 * X_{11} + 0.128 * X_{12} + 3.885 * X_7 + 0.700 * X_8$
    - $R^2 = 0.525$
- Low-Volume Interstate:
    - $Y = -112.755 + 1.578*\text{(lunch peak)} + 1.186*X_{11} - 0.014*X_{11}^2 + 1.208*X_{12} - 0.015*X_{12}^2 + 29.462*X_7 + 3.870*X_8 - 0.118*X_8^2$
    - $R^2 = 0.320$
- High-Volume Arterial:
    - $Y = -7.448 + 1.256*\text{(lunch period)} + 0.178*X_3 + 0.079*X_6 + 6.219*X_9$

  - $R^2 = 0.640$
- Low-Volume Arterial:
  - $Y = -19.308 + 1.161*(\text{lunch period}) + 0.980*X_{11} - 0.010*X_{11}^2 + 0.241*X_{12} - 0.002*X_{12}^2 + 22.762*X_9 + 0.604*X_8$
  - $R^2 = 0.516$

The high-volume arterial category produced the best performing model, as evidenced by the R square value of 0.640. The low-volume interstate category produced the weakest model, with an R square value of 0.320. This was anticipated given the low R square values observed during initial modeling efforts for this category. The intercepts in all models developed were negative, which was anticipated given the variables investigated in this study were all expected to result in an increase in rest area usage (positive constants).

The high-volume arterial model used the four separate distance variables while the other three models developed used combined upstream and downstream distance variables (upstream and downstream, nearest area and city, or shortest distance). The models developed for the high-volume interstate, low-volume interstate, and arterial categories included the upstream and downstream variables while the high-volume arterial used only the nearest city distance variable.

As anticipated, the models developed did not have a strong R square value due to the nature of the previous characterization of rest area usage. The low volume interstate category in particular provided many challenges. Based on this, more research may be needed regarding the modeling of rest area usage estimation. Also, statistical modeling techniques other than linear regression should be investigated. Based on the results of the modeling efforts described in the previous section, no model was viewed to be strong enough to warrant being employed by MDT to estimate rest area usage in the future. Rather, an alternative approach regarding future usage guidance was necessary. This will be discussed in the next chapter.

Diagnostic analysis was performed on the final linear regression models discussed previously. For the high-volume interstate model, several regression assumptions appeared to be violated. One such violation included the linearity assumption in which several of the independent variables appear to have non-linear relationships with the residuals. Another violation involved the homoscedastic residuals assumption in which the residuals appear to increase with larger values of the predicted value. The uncorrelated residuals assumption was violated indicating serial (time) correlation between the observations, which was anticipated given the data points were hourly traffic counts.

For the low-volume interstate model, the exogeneity assumption appeared to be violated in which several of the independent variables are dependent on one another. However, this was easily explained by the correlated variables being transformations of other independent variables.

For the high-volume arterial model, the exogeneity assumption appeared to be violated because the upstream area and downstream city distances appear to be correlated. While these may covary (one distance decreases as the other increases), it was hypothesized these are not correlated as one distance did not directly affect the other. Serial correlation was present in this dataset similar to the high-volume interstate model.

Heteroscedascity also appeared to be an issue similar to the high-volume interstate model.

For the low-volume arterial model, at first glance the linearity assumption appeared to be violated; however this can be accounted for by the introduction of transformations of the independent variables. Similar to the high-volume interstate and arterial models, serial correlation was present. The exogeneity assumption also appeared to be violated; however this is explained by the transformations of the distance variables. The homoscedastic residuals assumption was also violated, with the residuals increasing as the value of the predicted value increased. The diagnostic analyses of these linear regression models support the decision to use alternative methods in creating guidelines for MDT in rest area planning and design practice.

In examining water usage and wastewater generated at Montana rest area sites, it was found that, on average across all rest area sites, water usage was approximately 1.5 gallons per person for both facility types (interstate and arterial), all significantly lower than the value of 3.5 gallons per persons recommended by AASHTO for rest area planning purposes. Consequently, MDT may reconsider the usage values it employs in its planning efforts, at its discretion. This value would need to be applied to the level of traffic and rest area usage ultimately expected in the future and will also need to conform to the requirements set forth by the Montana DEQ for the design of water and wastewater systems. Recall the dwell time analysis performed for this research was not included in this chapter because the author was not involved in this analysis.

GUIDELINES ON REST AREA USAGE ESTIMATION IN MONTANA

This project investigated various aspects of rest area usage in the state of Montana. To the extent practical, the research team tried to investigate some of the variables that were thought to affect rest area usage, using data that was collected in the field or acquired from the Montana Department of Transportation. The analyses included in Chapter 4 showed that the selected aspects of usage varied in a broad range and that the variables investigated in this research project only explain some of the variation in rest area usage. Specifically, variables such as trip length, trip purpose, and traffic composition (local versus non-local drivers) may affect the percentage of traffic using a rest area, yet were not investigated by this project, primarily for reasons related to data availability and required resources. However, given the extensive amount of data collected in this project, this research offers valuable guidance to rest area usage in rural areas supported by extensive empirical observations. The value of this guidance is particularly evident given the limited research on rest area usage modeling, particularly for rural states. While valuable knowledge founded on practical experience exists among practitioners, this information is not available in a format for widespread use by the professional community.

This chapter utilizes the major research results presented in the previous chapters and expands the analyses on specific rest area usage aspects to offer some practical guidelines for rest area usage estimation in Montana.

Overall Usage at Rest Area

Table 78 provides a summary of the descriptive statistics for traffic usage that were discussed in the previous chapter, with additional statistics combining the data from the interstate and non-interstate facilities. Traffic usage is expressed as the percentage of mainline traffic stopping at the rest area. For dual interstate sites, the percentage applicable to specific direction of travel was used.

Table 78: Rest Area Usage Observations: Summary Statistics

Mean	Median	Mode	Standard Deviation	80th Percentile	85th Percentile	90th Percentile	95th Percentile	Range
High-Volume Interstate								
9.92	9.09	9	6.45	15.25	15.58	18.11	22.55	0-50
Low-Volume Interstate								
8.69	7.69	8	7.21	14.01	13.76	15.68	19.03	0-100
High-Volume Arterial								
9.14	7.14	5	7.71	20.6	17.37	21.18	25	0-35.8
Low-Volume Arterial								
13.39	7.73	7	18.05	17.95	25.07	33.33	50	0-100
Interstate								
9.5	8.5	8	6.75	13.31	14.95	17.02	21.57	0-100
Arterial								
12.2	7.62	5	15.95	16.74	21.88	28.85	43.14	0-100
Overall								
10.27	8.33	5	10.32	14	16.12	19.38	26.02	0-100

As shown in Table 78, the rest areas in the low-volume arterial category are associated with higher mean rest area traffic usage and standard deviation compared with the other three categories. This is also applicable to the percentile usage values. For the other three categories, the mean rest area usage and standard deviation are relatively close to one another.

An important issue that should be discussed here is the data collected at rest areas in the high-volume arterial category. While selected based on traffic level and highway class, this category included only four rest areas that did not share many other similar attributes. It was observed that the rest area usage at Bridger (the control station for the group) was notably lower than that at the other three rest areas, which could be related to the highly seasonal and recreational traffic on US Route 310. Further, two of the four rest areas in this category are adjacent to weigh station facilities that may have an influence on rest area usage (induced demand). On the other hand, the low-volume arterial category involved a higher number of sites that are considered more uniform or homogeneous. *Therefore, there is strong evidence to believe that traffic usage observations at rest areas in the low-volume category are more representative of rest areas on arterials in general than those collected from rest areas in the high-volume category*.

One other important observation about Table 78 is the wide range of rest area usage observations, especially at those locations on low-volume interstate and arterial categories. These are believed to be observations from the very low volume off-peak periods, especially after midnight and during the early morning hours. From a practical standpoint, rest area usage during these very low-volume periods has less significance in the planning and design of rest area facilities. Therefore, it may be more meaningful if the values in Table 78 are reproduced using the mid-day peak period, as the usage during this period is what matters most in the planning and design of rest area facilities. Table

79 shows the rest area traffic usage descriptive statistics for the peak daytime period between 9:00 a.m. and 4:00 p.m.

Table 79: Descriptive Statistics for Rest Area Traffic Usage
Between 9:00 a.m. and 4:00 p.m.

Mean	Median	Mode	Standard Deviation	80th Percentile	85th Percentile	90th Percentile	95th Percentile	Range
High-Volume Interstate								
11.45	10.86	9	6.48	15.25	16.62	19.36	24.38	1.12-36.91
Low-Volume Interstate								
10.36	9.83	9	4.55	14.01	15.06	16.36	17.87	2.09-29.52
High-Volume Arterial								
13.36	11.74	6	7.63	20.60	22.41	24.34	27.33	1.37-35.84
Low-Volume Arterial								
16.17	11.38	7	12.64	22.68	28.57	35.51	46.59	1.20-59.74
Interstate								
11.02	10.42	9	5.82	14.73	16.01	17.72	22.56	1.12-36.91
Arterial								
15.39	11.46	8	11.52	21.36	25.63	31.75	43.60	1.12-59.74
Overall								
12.40	10.70	9	8.32	15.98	18.32	22.25	28.50	1.12-59.74

Excluding off-peak hours has resulted in lower variation in rest area usage and a more realistic range of usage values, as shown in Table 79. The percentages of mainline traffic using the rest areas are generally higher during the peak period, which is evident in all of the four categories of rest areas.

Upon careful examination of this table, it may be reasonable to suggest that using 18 percent of the interstate mainline peak traffic as a baseline rest area traffic usage will ensure that the rest area design will accommodate the peak mid-day traffic around 90 percent of the time. Similarly, using a baseline rest area usage of 32 percent at rest areas on arterials will accommodate the peak mid-day traffic slightly less than 90 percent of the time. The latter recommended value is slightly lower than the 90th percentile due to the high variation in usage observations associated with rest areas in the low-volume arterial category.

Guideline #1: In rest area design, a baseline rest area usage of 16% and 25% of mainline peak traffic may be used at rest areas on interstate highways and rural arterials, respectively.

Heavy Vehicle Usage

In discussing bus and commercial vehicle usage at rest areas in Chapter 4, the mainline proportion did not exhibit a consistent relationship with the percentage of rest area usage. Therefore, a more in-depth analysis was performed on the three control stations for which actual mainline truck proportion data was available (Divide SB, Emigrant, and Greycliff EB). The average percentage of trucks at the Emigrant rest area was found to be very low (around 3.1%) and as such, using this site may not be appropriate to show the effect of commercial vehicles on rest area usage. Using data from the respective mainline ATRs, the mainline truck proportion was compared to the percentage of rest area usage by hour. The results of this analysis at the Greycliff EB and Divide SB rest areas are presented in Table 80.

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Table 80: Mainline Truck Proportion vs. Percent Rest Area Usage (all day)

% Buses and Commercial Vehicle	0 to 10	10 to 20	20 to 30	30 to 40	40+
Greycliff Eastbound (2009 average % trucks = 22.9%)					
% Rest Area Usage	11.8	10.3	9.8	11.5	14.5
Divide Southbound (2009 average % trucks = 22.2%)					
% Rest Area Usage	12.3	11.3	9.4	9.4	10.1

A careful examination of Table 80 shows that rest area usage slightly declines with the increase in the percentage of buses and commercial vehicles up to around 30 percent and then starts to increase again when the percentage of buses and commercial vehicles reaches 40 percent or higher. It is suspected that the increase in usage associated with the high commercial vehicle percentage is related to off-peak late night and early morning hours. Examination of the respective data has confirmed this observation, as shown in Figure 80.

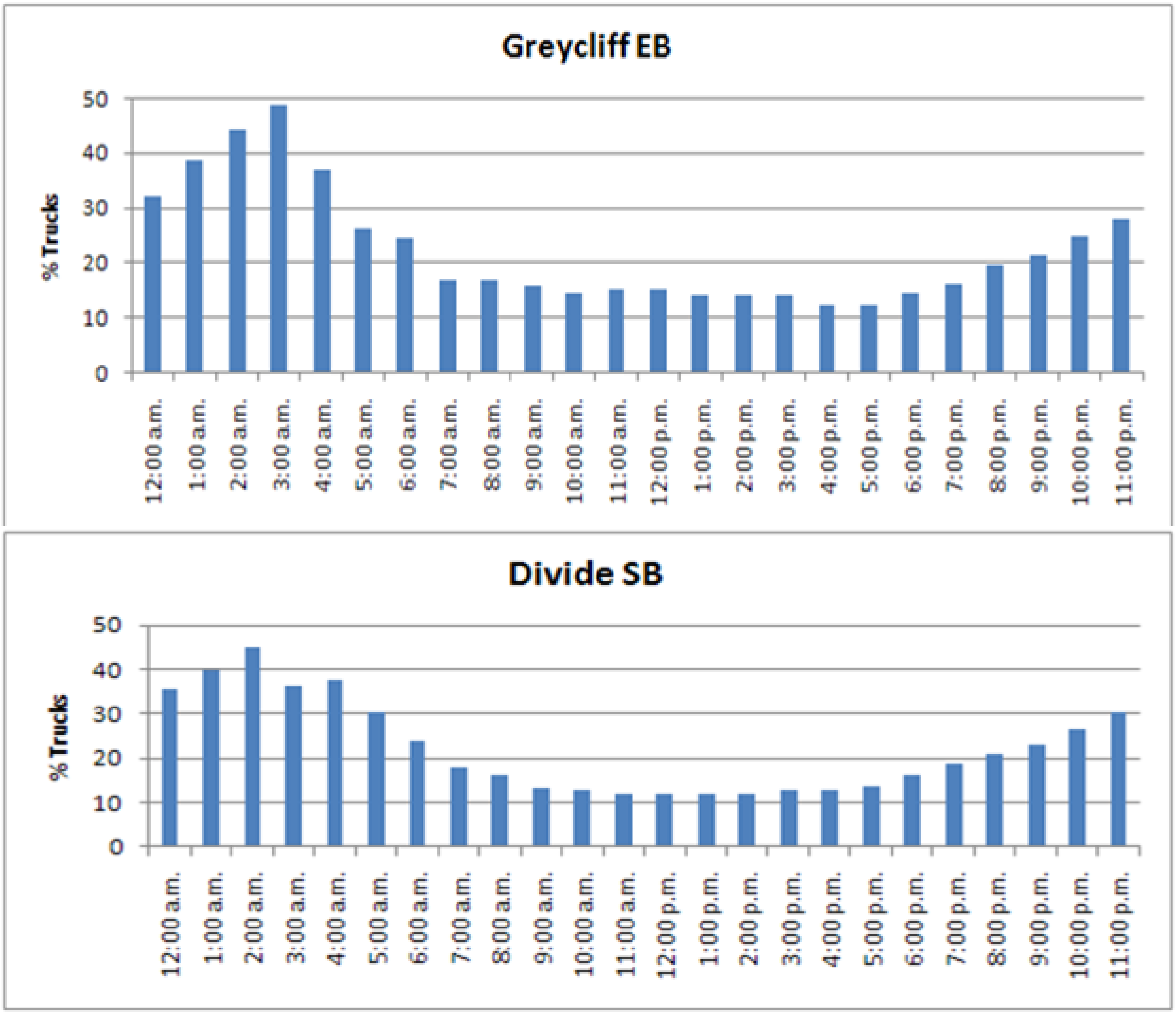

Figure 80: Daily Variation in Mainline Percentage of Trucks at the Greycliff EB and Divide SB Rest Areas

Based on the patterns shown in Figure 80, it was decided to exclude the off-peak period from the analysis. Table 81 shows the rest area usage for various levels of mainline bus and commercial vehicle percentages for the period between 8:00 a.m. and 8:00 p.m.

Table 81: Mainline Truck Proportion vs. Percent Rest Area Usage (8 a.m. – 8 p.m.)

% Trucks	0 to 10	10 to 20	20 to 30	30+
Greycliff Eastbound (2009 average % trucks = 21.2%)				
% Rest Area Usage	10.1	11.0	10.8	---
Divide Southbound (2009 average % trucks = 19.4%)				
% Rest Area Usage	12.7	12.4	11.0	14.3*

*This value came from only 8 observations.

Table 81 shows that there is no clear trend related to the effect of buses and commercial vehicles on the rest area usage. The increase at Divide SB associated with the high truck percentage is based on a few observations and therefore cannot be treated with certainty. Based on the values presented in Table 81, it is reasonable not to adjust rest area usage based on daytime truck percentage.

Guideline #2: There is no need to adjust the baseline rest area usage (percent of mainline traffic) for the peak daytime period based on the overall percentage of buses and commercial vehicles in the mainline served by the rest area.

To further examine this trend, the average bus and commercial vehicle proportion was calculated during the designated peak period (9 a.m. - 4 p.m.) and compared to the overall average truck proportion, presented in Table 82. This analysis proves the truck proportion increases significantly during off-peak hours.

Table 82: Mainline Truck Proportion vs. Percent Rest Area Usage

Site	**Peak Period % Buses and Commercial Vehicles**	**Overall % Buses and Commercial Vehicles**	**Peak-to-overall ratio**	**Night hours (12 a.m. – 6 a.m.)**	**Night-to-overall ratio**
Divide SB	12.5	22.2	0.563	35.5	1.601
Emigrant	2.2	3.0	0.743	6.4	2.14
Greycliff EB	14.7	22.4	0.655	35.9	1.603

Based on the percentages of trucks presented in Table 82, it would be reasonable to use 70 percent of the overall bus and commercial vehicle percentage for the highway served by the rest area in determining the number of truck parking stalls required at a particular rest area. This estimation is relatively conservative as, at most sites investigated by this study; it exceeds the actual number of trucks using the rest area during the peak design hours. This is especially true for rest areas that are located at highways that belong to the low-volume interstate and arterial categories.

Guideline #3: For planning and design purposes, it is reasonable to assume the percentage of buses and commercial vehicles during the design peak period as equivalent to 70 percent of the overall bus and commercial vehicle percentage for the mainline served by the rest area.

As parking stalls for commercial vehicles are different from those used for smaller vehicles, it was deemed appropriate to examine the bus and commercial vehicle counts and percentages entering the Greycliff EB and Divide SB rest areas. The results of this analysis are shown in Figure 82. As shown in this figure, the number of buses and commercial vehicles entering rest areas on average is higher during the day, consistent with expectations, as more travel occurs during the day. Specifically, the figure shows that the number of buses and commercial vehicles using a rest area peaks mid-day around noon despite the fact that the percentage of trucks in the mainline traffic stream peaks after midnight (roughly during the period between 1:00 a.m. and 4:00 a.m.). Further, the figure shows that the percentage of trucks entering the rest areas during the night is notably higher than that during daytime hours. This trend is largely consistent with the variation in mainline trucks percentage shown in Figure 80. Therefore, an estimate of mid-day and nighttime bus and commercial vehicle counts along with the expected dwell times are important inputs for the determination of parking needs at rest areas.

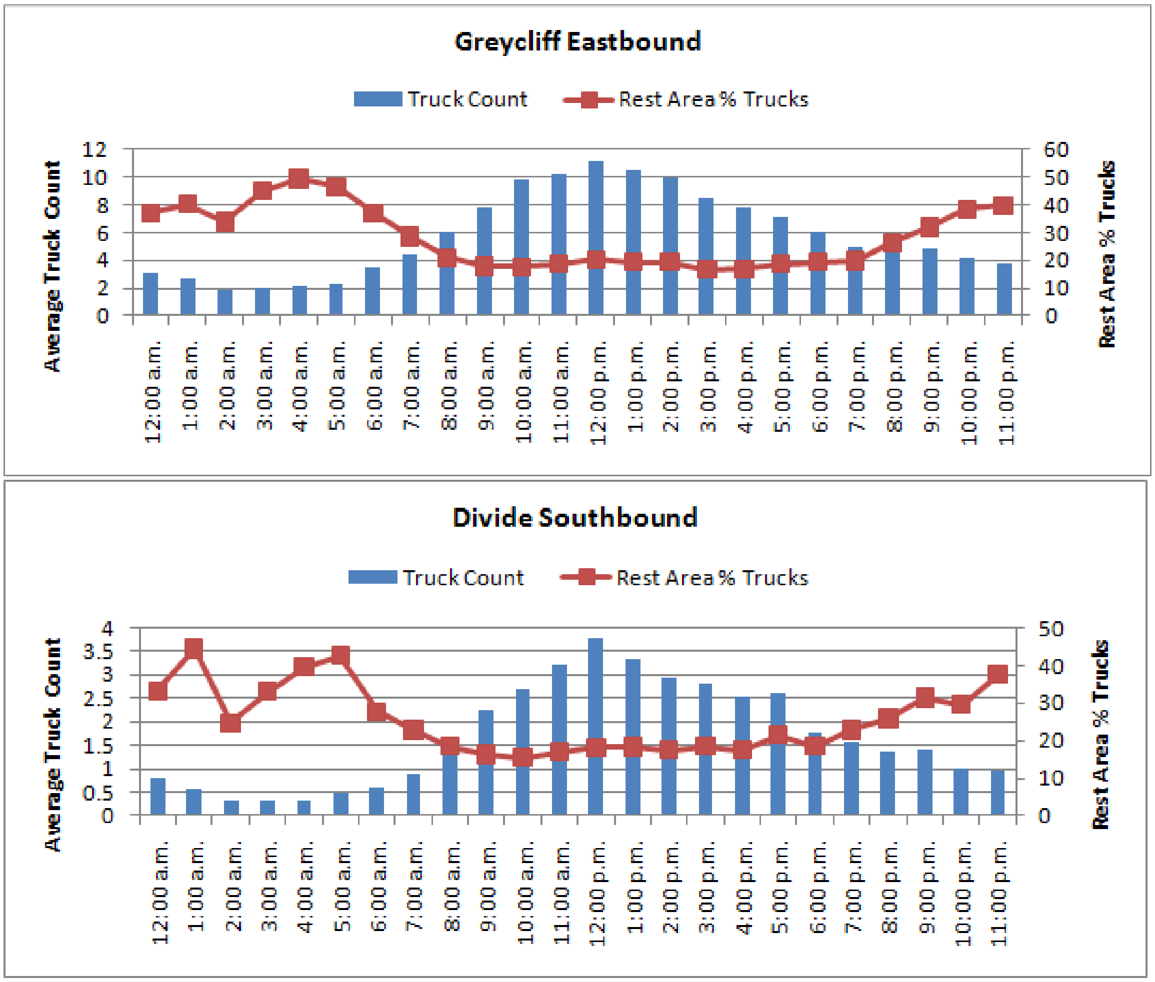

Figure 81: Hourly Rest Area Truck Counts and Percentages at the Greycliff EB and Divide SB Sites

Parking Dwell Times at Rest Areas

Parking dwell time is a critical input in determining the parking demand and design capacity at a particular rest area both for passenger and commercial vehicles. There is minimal information in the *Guide for Development of Rest Areas on Major Arterials and Freeways* (AASHTO 2001) about the dwell times used in the planning and design of rest areas. In one section of the guide, parking dwell times of 15 minutes for passenger vehicles and 20 minutes for trucks were labeled as "normal" and used in a formula to find the number of parking stalls needed for passenger vehicles and trucks. In the Guide's appendix, a simple analysis to estimate truck parking spaces needed (quoted from an FHWA report) used 30 minutes as an average dwell time for trucks. The work performed during this research involved detailed investigation on parking dwell time at three different Montana rest areas to better understand the magnitude and trends of parking dwell time that are essential for determining parking needs at rest areas.

When data were separated by day and night, average dwell time during the day was found to be significantly lower than that during the night. The mean values for various vehicle types are shown in Table 83. At the three rest areas investigated, the mean truck dwell time during the night is roughly around 4 to 5 times that during the day. However, as discussed in the previous section, the number of trucks using the rest area during daytime is higher than that during nighttime. Therefore, both truck count and mean dwell time during the day and night should be used in determining the number of truck parking stalls needed at the subject rest area. This is not the case with the passenger vehicles, where daytime counts usually dictate the parking needs at the rest area.

Table 83: Mean Dwell Time by Vehicle Type During Day and Night at Study Sites

Mean Dwell Time (min)			
Location	**Vehicle Type**	**Day**	**Night**
Greycliff EB	Cars	00:10:31	01:13:35
	Trucks	00:34:00	03:08:00
	RVs	00:15:37	03:45:00
Divide SB	Cars	00:10:47	00:50:14
	Trucks	00:37:50	03:21:42
	RVs	00:14:44	01:07:04
Clearwater Junction	Cars	00:09:33	00:22:18
	Trucks	0025:25	01:36:22
	RVs	00:26:38	---

--- Value omitted for lack of adequate empirical observations.

Guideline #4: Passenger vehicle traffic counts and average dwell time during the daytime peak period should be used in the determination of passenger car parking needs at the rest area.

Guideline #5: Both commercial vehicle counts and dwell times during the daytime peak period and the nighttime off-peak period should be used in determining truck parking needs at the rest area.

Weigh Stations

As discussed in the previous chapter, the operation of a weigh station in conjunction with a rest area appeared to increase the rest area usage at a particular site. To further examine this observation, the percentage of rest area usage was calculated during periods when the weigh stations were both closed and open. Only daytime hours when the weigh stations were in operation were used in this comparison.

As shown in Table 84, the rest area usage dramatically increased during the hours of weigh station operation at the Culbertson and Clearwater Junction rest areas, but exhibited almost no change at the Armington rest area. Armington rest area and weigh station are set apart, though they share the same driveway access. This differs slightly from the layout of the Culbertson and Clearwater Junction which may partly explain the lack of change in usage observed elsewhere. Another possible factor behind this is the proximity to major cities. Armington is located approximately 25 miles from the city of Great Falls, Clearwater Junction is approximately 40 miles from Missoula, while the Culbertson rest area is approximately 90 miles from Glendive. This may have an effect on the induced demand on the rest area from users of the weigh station.

Table 84: Comparison of Rest Area Usage with Weigh Station Operation

Rest Area Site	Weigh Station Closed	Weigh Station Open	Hours of Operation
Armington	10.3%	10.1%	9 a.m. to 5 p.m.
Clearwater Junction	8.7%	18.5%	10 a.m. to 3 p.m.
Culbertson	13.1%	50.8%	9 a.m. to 4 p.m.

To further examine this observation, the proportion of trucks in the traffic entering each of the three rest areas was calculated during these same time periods when the weigh stations were closed and open. Results are shown in Table 85.

Table 85: Comparison of Rest Area Count Truck Percentage with and without Weigh Station Operation

Rest Area Site	Weigh Station Closed	Weigh Station Open	Hours of Operation
Armington	2.3%	4.2%	9 a.m. to 5 p.m.
Clearwater Junction	4.5%	17.3%	10 a.m. to 3 p.m.
Culbertson	10.9%	34.3%	9 a.m. to 4 p.m.

As shown in Table 85, the proportion of trucks at all three sites notably increased when the weigh stations were in operation. However, the magnitude of this increase is not consistent among the three sites investigated. Specifically, the increases at the Clearwater Junction and Culbertson sites were more profound than that at the Armington rest area. Overall, results suggest that a weigh station in conjunction of a rest area will most likely increase the commercial vehicle demand on the rest area sharing the same location. The amount of the induced commercial truck demand is believed to be site specific and needs to be estimated on a case-by-case basis.

Guideline #6: A weigh station sharing the site with a rest area will most likely increase the commercial truck demand on the rest area when weigh station is in operation. The amount of the induced heavy vehicle demand needs to be estimated on a case-by-case basis.

Rest Area Condition

Rest area condition was investigated in this research as one of the variables that may have an effect on rest area traffic usage. Figure 82 shows the average rest area usage for rest areas classified as being in good, fair, and poor condition. The source of these condition ratings was MDT's Planning Systems Data & Statistics Bureau. A good condition rest area was defined as one which is of newer construction and has been well maintained. A fair rest area was one which was likely to be of older construction and could likely use renovation, with the site being kept adequately maintained. A poor condition rest area was one which was likely older and nearing the end of its useful life. It should be noted that rest area condition assessment according to this scheme was conducted in a somewhat qualitative manner. Eleven sites were given a "poor" rating while 20 and 13 sites were given “fair” and “good” ratings, respectively. As shown in Figure 82, rest areas classified as being in “good” condition were associated with higher usage than those classified as being in “poor” or “fair” condition. However, almost no distinction in usage is apparent between rest areas classified as being in “fair” condition and those classified as being in “poor” condition.

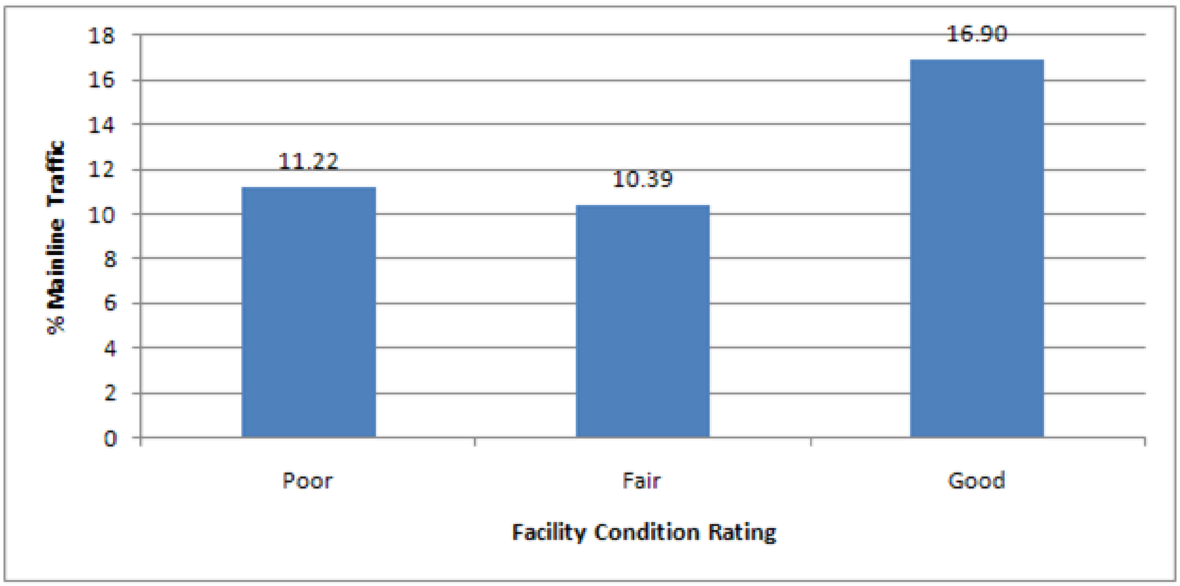

Figure 82: Facility Condition vs. Rest Area Usage - Overall

To further examine the effect of rest area condition on traffic usage, the mean usage (in terms of percentage mainline traffic) is provided for rest areas that are in good condition versus those that are in poor/fair condition for the four highway categories as shown in Table 86. This table shows that the rest area usage for “good” condition is higher than that for the combined poor and fair conditions at high-volume interstate and low volume arterial categories, about the same for high-volume arterial, and slightly lower for low-volume interstate. Therefore, the figures presented in this table suggest the lack of adequate and consistent evidence about the effect of rest area condition on traffic usage.

Table 86: Rest Area Usage by Condition and Highway Category

Category	Poor/Fair	Good	Good-to-Poor/Fair Ratio
High-Volume Interstate	9.4	11.0	1.17
Low-Volume Interstate	8.8	7.9	0.90
High-Volume Arterial	9.0	9.3	1.03
Low-Volume Arterial	11.4	16.2	1.42

Guideline #7: While rest area condition may affect traffic usage, it is recommended not to adjust the baseline usage for rest area condition due to lack of consistent empirical evidence.

Seasonal Variation in Rest Area Usage

In this study, rest area traffic usage data were collected for the most part during the summer season (data at a few rest areas were collected during September 2009). Therefore, the percentages of mainline traffic using the rest area that were discussed previously should largely reflect the peak summer season. In using these percentages for the planning and design of rest areas, it is important for the Montana Department of Transportation to use mainline traffic counts which represent the peak summer season.

Guideline #8: For rest area planning and design purposes, it is important to use mainline traffic counts that reflect the peak summer season.

Patron Demand on Rest Area Facilities

Many aspects of rest area design rely directly or indirectly on vehicle counts. One indirect use of vehicle count data is a determination of the number of rest area patrons. Such information is important in the sizing of rest area facilities, from the size of the overall building(s) to specifics such as restroom fixtures. As discussed in previous chapters, this research has established the relationship between the number of vehicles accessing the rest area facility and the number of patrons using the rest area building at four study sites: Divide southbound, Greycliff eastbound, Bridger, and Emigrant rest areas.

Based on the results of the analysis presented earlier, it seems reasonable to recommend a value of 1.5 patrons per vehicle accessing the rest area facility to be employed in Montana rest area design. This figure is considered conservative as it is slightly higher than the values observed at all rest areas except the Emigrant rest area where the corresponding value was 1.78. This higher value is believed to be related to the highly recreational traffic and the abnormally low percentage of trucks associated with this particular rest area.

Guideline # 9: For rest area planning and design purposes, a rate of 1.5 may be used in estimating the number of patrons using the rest area building based on the number of vehicles stopping at the rest area facility.

Water Usage at Rest Areas

The analysis of the average amount of water used and wastewater generated per patron at a rest area was provided in the previous chapter. This was accomplished by dividing a specific day's water meter reading by the number of patrons at the rest area for that day. A summary of the results of this analysis is provided in Table 87 below:

Table 87: Water Usage Summary of Results

	Mean (gal/patron)	**Median (gal/patron)**	**85^{th} Percentile**	**90^{th} Percentile**	**95^{th} Percentile**
Interstate	1.45	1.24	2.53	2.84	3.32
Arterial	1.46	1.25	2.36	2.58	3.00
Overall	1.45	1.24	2.50	2.80	3.26

It is evident that the differences in water usage between those on interstate and arterial highways are relatively small. Therefore, the overall statistics are more important to the current discussion about water usage at rest areas in Montana. As shown in this table, the average patron water usage at all rest areas is approximately 1.5 gallons. The usage that occurred most often at all rest areas was 2.0 gallons per patron and the 85^{th} percentile at all rest areas is 2.5. As the more up-to-date low flow fixtures that are used in all current rest area projects normally result in lower water usage, and the fact that the statistics shown in this table are based on all rest areas including some of the older ones with higher water usage, it is both reasonable and conservative to recommend average water usage per patron of 2.0 gallons.

Guideline # 10: It is recommended that the MDT use an average water usage of 2.0 gallons per patron in planning Montana water and wastewater systems at current rest area projects. The ultimate value employed will also need to conform to the requirements set forth by the Montana Department of Environmental Quality (DEQ) for the design of such systems, specifically wastewater treatment systems at sites where city sewer access is not available.

Rest Areas Usage Estimation Example

To appreciate the differences and similarities between the guidelines developed in this research project and those provided by AASHTO (AASHTO, 2001), it would be useful to go over an example where both recommended guidelines are applied to a particular rest area. The Greycliff eastbound rest area was selected in this example for the purpose of demonstrating how the mainline average daily traffic could be used in estimating the number of parking stalls by vehicle type, number of patrons accessing the rest area, number of toilets required and water usage. The guidelines provided in this chapter and the equations provided by AASHTO (AASHTO, 2001) were used in usage estimation calculations. The AASHTO equations used in this example are presented below:

Number of parking spaces:

$$\mathrm{N_c} \text{ and } N_t = \frac{ADT * P * DH * D_c * PF * VHS}{60}$$

Where:

N_c = Number of passenger vehicle parking spaces

N_t	= Number of commercial vehicle parking spaces
ADT	= Average daily traffic
P	= proportion of mainline traffic stopping
DH	= design hourly factor
D_c	= proportion of cars using facility (D_t when computing commercial vehicle parking)
PF	= peak factor, ratio of average-day usage during the 5 peak summer months compared with the average over the entire year
VHS	= average dwell time

Number of Restroom Stalls:

T = ADT*UF*YV*B*PF*P*UHF
Where:

T	= Number of restroom stalls
ADT	= Average Daily Traffic
UV	= restroom users per vehicle
B	= ratio of design hourly volume to ADT
PF	= Peak Factor, the ratio of the average day usage during the five summer months of peak usage compared with the average day usage over the entire year
P	= total percent of traffic stopping at the rest area
UHF	= restroom users per hour per fixture based on 2 minute cycle

Water Usage:

PHD = ADT*B*PF*P*UV*Gallons + Employee flow
Where:

PHD	= Peak Hourly Demand
ADT	= Average Daily Traffic
B	= ratio of design hourly volume to ADT
PF	= Peak Factor, the ratio of the average day used during the five summer months of peak usage compared with the average day usage over the entire year
P	= total percent of traffic stopping at the rest area
UV	= restroom users per vehicle
Gallons	= recommended gallons of water use per user

Employee flow = water required by maintenance employee (i.e. cleaning)

Using the above equations, the guidelines presented in this chapter, and the average daily traffic borrowed from the directional MDT traffic data for 2008, usage estimation was calculated and results are presented in Table 89. The data compiled for use in estimation calculation is presented in Table 88. For brevity, estimation calculations are not presented in this section.

Table 88: Data Elements Employed in Calculations

Variable	**AASHTO**	**Recommended Guidelines**	**Notes**
Traffic	4900 (ADT)	346 vph (day) 52 vph (night)	ADT and hourly estimates are based on MDT ATR data
P	0.16 (1)	0.16 (2)	(1) Determined by AASHTO decision rule (2) Based on Guideline #1
DH	0.15	N/A	AASHTO recommended value
D_c	0.75	0.853	Based on measured commercial vehicle day percentage of 0.147
D_t	0.25	0.1 (day), 0.25 (night)	Measured by the research
PF	1.8	1.8	AASHTO recommended value
VHS	15 for passenger 20 for commercial	10 for passenger 34 for commercial (day) 188 commercial (night)	Measured by the research
UV	1.3	1.5	Measured by the research
Gallons	3.5	2.0	Measured by the research

Table 89: Comparison of Design Element Results

	AASHTO Figures	**Ch 5 Recommended Guidelines**
Passenger vehicle stalls	39	15
Commercial vehicle stalls	18	6 (day) 12 (night)
Restroom stalls	5 (women), 4 (men)	3 (women), 2 (men)
Water usage (gallons)	963	635

As the results in Table 89 indicate, various differences resulted in the design elements computed using AASHTO's guidance compared to that employing the guidance recommended in this chapter. The first difference is that of the parking stalls required for the site. Through the use of the different variable inputs developed by the research, namely dwell time, as well as the proportion of passenger vehicles and commercial vehicles using the rest areas, the number of parking stalls was determined. For passenger vehicles, this ranged from 39 using the AASHTO guidance to 15 using the research guidance. This represents a significant difference from a planning and design standpoint, as fewer required stalls have the potential to translate into construction and maintenance savings. When determining the number of commercial vehicle stalls, the AASHTO guidance determined 18 stalls were necessary, while the guidance of this chapter found that 12 stalls were necessary. Once again, this represents the potential for design savings. Please note that the number of parking stalls calculated using research recommended guidelines are based on the 85^{th} percentile usage, suggesting the parking capacity could be exceeded approximately 15 percent of the time during the peak hour period. The recommended guidelines allow for more conservative estimates should higher percentile values be selected.

The number of restroom stalls required displayed slight differences. Using the AASHTO guidance, a total of nine stalls would be required, while the research guidance indicated only five stalls would be necessary. This represented a difference of two men's stalls and two women's stalls which presents additional potential for construction and maintenance savings.

Perhaps the most significant result of this limited evaluation was that of estimated water usage. As the table indicates, when AASHTO's recommended values are employed, water usage was estimated to be 963 gallons. Based on the guidance of this chapter, an alternative value for water usage of 635 gallons was determined, a difference of 328 gallons. This result has profound impacts on rest area design, both in terms of water usage (well design, etc.) and wastewater generation (sewer and septic designs). As it appears that AASHTO calculations overestimate water usage, it is possible that systems are currently being overdesigned, with corresponding financial implications. Indeed, when referring back to the data recorded for this site, it was found that on average 550 gallons of water were being used per day (with corresponding assumed wastewater generated). Consequently, the use of the 2.0 gallons per user metric has produced an overestimation of 85 gallons. Whether this difference constitutes a reasonable margin of safety in design is not known; however it does illustrate the shortcoming of the continued use of AASHTO's 3.5 gallons per user figure.

Chapter Summary

This chapter utilized the major research results presented in the previous chapter in developing a set of guidelines that is intended to help the Montana Department of Transportation in planning and designing future rest area construction and rehabilitation projects. The recommended guidelines presented in this chapter are listed below:

1) In rest area planning and design, a baseline rest area traffic usage of 16% and 25% of mainline peak traffic may be used at rest areas on interstate and arterial highways respectively.

2) There is no need to adjust the baseline rest area usage (percent of mainline traffic) for the peak daytime period based on the overall percentage of tucks in the mainline served by the rest area.

3) It is reasonable to assume the percentage of trucks during the design peak period as equivalent to 70 percent of the overall truck percentage for the mainline served by the rest area.

4) Passenger vehicle traffic counts and average dwell time during the daytime peak period should be used in the determination of passenger vehicle parking needs at the rest area.

5) Both bus and commercial vehicle counts and dwell times during the daytime peak period and the nighttime off-peak period should be used in determining parking needs at the rest area.

6) A weigh station sharing the site with a rest area will most likely increase the commercial truck demand on the rest area when the weigh station is in operation. The amount of the induced heavy vehicle demand needs to be estimated on a case-by-case basis.

7) While rest area condition may affect traffic usage, it is recommended not to adjust the baseline usage for rest area condition due to lack of consistent empirical evidence.

8) For rest area planning and design purposes, it is important to use mainline traffic counts that reflect the peak summer season.

9) A rate of 1.5 may be used in estimating the number of patrons using the rest area building based on the number of vehicles stopping at the rest area facility.

10) It is recommended that MDT use an average water usage of 2.0 gallons per patron in planning Montana water and wastewater systems at current rest area projects. The ultimate value employed will also need to conform to the requirements set forth by the Montana Department of Environmental Quality (DEQ) for the design of such systems.

Recommendations for Further Research

Based on the results of these analyses, it is believed more research should be conducted regarding the estimation of rest area usage in the future. One limitation of this research is all variables considered were related to rest area and mainline traffic properties (distances, facility condition, % trucks, etc.). The effects of trip characteristics such as trip length, trip type (commuter versus non-commuter), as well as the proportion of out-of-state vehicles could be other variables considered in future analyses.

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