Final report of ITS Center project: Truck stop information

A Research Project Report

For the National ITS Implementation Research Center

A U.S. DOT University Transportation Center

Estimation of the Demand for Commercial Truck Parking on Interstate Highways in Virginia

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A Research Project Report
For the Mid-Atlantic Universities Transportation Center (MAUTC)
A U.S. DOT University Transportation Center

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1 Abstract

The steady growth of commercial truck traveling on most Interstate and primary highways has resulted in increasing demand for both public rest areas and private truck stops in Virginia. In addition, inadequate parking spaces for commercial trucks may be a contributing factor to drivers' fatigue and the unsafe practices of parking commercial trucks on highway shoulders and interchange ramps. This study developed a methodology to determine the supply and demand for commercial truck parking along highway system. In this study, *supply* was defined as the number of parking spaces available for commercial truck parking, and *demand* was defined as the sum of the parking accumulation and the illegal parking at a given time.

A two-phase research project on the *Supply And Demand For Commercial Truck Parking Facilities in Virginia* has been carried out to evaluate truck driver parking needs. Phase one of this study developed a methodology to determine the supply and demand for commercial truck parking using Interstate-81 in Virginia as a case study. Phase two expanded the study to other Interstate and primary highways in Virginia, checked the

applicability of the parking demand model developed in phase one and developed new models for the other highways in Virginia.

Extensive data on the characteristics of commercial truck parking including parking duration and accumulation for different times of day were obtained. Detailed information was also obtained on the characteristics of each truck stop and rest area, including the location, number and types of parking spaces, and availability of other amenities, such as restaurants and showers. Two types of questionnaire surveys were conducted. The first survey involved truck drivers, and the second survey involved truck stop managers/owners. The survey data were used to develop models to describe the relationship between parking accumulation and independent variables such as traffic volume on the highway, truck percentage, parking duration, and the distance from a highway to a truck stop. After testing the applicability of the models, they were then used to estimate commercial truck parking demand in 2010 and 2020. Deficiencies of parking spaces in supply with respect to the estimated demand were then determined for each truck stop and the entire highway system.

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2 Introduction

The lack of adequate parking spaces for commercial trucks at rest areas and truck stops on the Interstate highway system throughout the nation in recent years is a serious concern for both the public and private industries using these facilities. Several studies have indicated the inadequacy of parking facilities for commercial trucks may be associated with fatigue related crashes involving these vehicles.[1, 2, 3, 4] In addition, truck drivers who cannot find parking spaces at these facilities often choose to park on ramps and the roadway shoulders, which often results in accelerated deterioration of the pavement.[5, 6, 7]

The inadequacy of parking facilities for commercial trucks, particular during late-evenings and early mornings is a phenomenon that exhibits itself on Virginia Interstate system. In order to take suitable actions, the findings of this research study will help the decision makers make better assumptions on the supply and demand for commercial truck parking spaces. This should include the specific days and times of day that maximum accumulation occurs, and the number of parking spaces available for commercial truck parking. Unfortunately, this information is not available for the highway system in Virginia. Other national studies[10, 11] have investigated the demand for and supply of truck parking facilities; however, the results of these studies cannot be directly applied to Virginia highways without further evaluation for several reasons. First, most studies focused on rest area parking or were lack of detailed information on truck stop. However, over 80% of commercial truck parking spaces are provided by private organizations. Second, truck drivers are only allowed a maximum stay of two hours at the rest areas in Virginia, which is clearly inadequate for proper rest. In this study, investigators analyzed the demand for commercial truck parking on Virginia's highway system, then provided a detailed report on the parking availability at truck stops and rest areas.

2.1 Background

Attention on the adequacy of places for truck drivers to stop and rest continues to increase as the growth in trucking transportation occurs. The Hours-of-Service (HOS) rules, established in 1937 by the Interstate Commerce Commission, limits the number of hours that truck drivers may drive and be on duty. This has directly created a demand for parking spaces for truck drivers can stop and rest. The number of parking spaces at rest areas for short-term rest of car and truck drivers has been increasing since President Eisenhower signed the Federal Aid Highway Act authorizing construction of the Interstate Defense Highway System throughout the United States in 1956. This act has led to the rapid growth in the trucking industry, which resulted in the construction of private truck stops and travel plazas along Interstate corridors to provide such services as fuel, food, showers, truck repair and wash, in addition to overnight parking spaces. The acceptable balance between truck parking demand and spaces available became difficult to maintain after the deregulation of trucking industry in the early 1980s.

The Virginia Transportation Research Council (VTRC) has been conducting a study to investigate the supply and demand for truck parking facilities in Virginia since 1999. The ultimate objective of this study was to develop a real-time information system to truck drivers on Interstate highways in Virginia. After the researchers met with several district traffic engineers and transportation researchers, investigators found that it was necessary to conduct in several phases. The first phase was to develop a method for estimating the supply and demand for commercial truck parking on Interstate-81 in Virginia as a case study. The second phase is to estimate the commercial truck parking demand on major highways and Interstate in Virginia using the same procedure in phase one. The third phase will be the development of a real-time parking information system for commercial drivers. The authors completed the phase I study in which a methodology was developed for estimating commercial truck parking demand. A final report has been published on the phase I study .[12] This report will report the research process and findings of the second phase.

2.2 Problem Statement

In order to evaluate the adequacy of parking spaces for commercial trucks along the Interstate and primary highways in Virginia, information on available parking spaces and parking demand of commercial trucks is necessary. Some of this information was available, while a majority was not. Examples of available information included: the number of public rest areas, their locations and the number of parking spaces. Examples of unavailable information include the number of parking spaces for commercial trucks at individual private truck stops along Interstate and primary highways in Virginia, the average duration for different times of the day and other characteristics of commercial truck parking demands. Also results obtained during the case study on I-81 identified discrepancies between the numbers of parking spaces actually counted and those documented for many truck stops. Although two models were developed for relating parking accumulation and certain other independent variables for the truck stops along Interstate 81, there was no guarantee that the models would adequately describe parking accumulation at truck stops on other Interstate and primary highways in Virginia. It was therefore necessary for the existing models to be tested at different locations, and be calibrated to fit the characteristics at different locations, and if necessary to develop new models for different locations. In order to carry this out, adequate data on accumulation and duration were needed. This requires the extensive amount of data collection on accumulation and duration at the different locations in Virginia.

2.3 Purpose and Scope

The purpose of this study was to develop and apply a methodology for estimating the supply and demand for commercial truck parking on the Interstate and primary highways, in order to determine the shortage, if any. Appropriate models that describe the relationship between parking accumulation and the independent variables were needed for this purpose.

All the Interstate highways except I-81 and some primary highways in Virginia were examined in this phase II study. Interstate 81 was excluded, as it was the subject link of the phase I study. Although, the topic is only for Interstate highways in Virginia, most of the primary highways were also included in the initial stage of this study. However, the eastern sections of 460, 360, 58 and 13 were not included due to limitation of manpower and time. At the time of the study, we found no other commercial truck parking facilities satisfying the site criterion for this study on other primary roads that had been examined except US 29. Only truck stops that had fifteen overnight parking spaces or more were included in this study. Forty-one public rest areas and the fifty-four private truck stops in Virginia were included in this study. The following highways were included in this phase:

- Interstate highways: I-64, I-66, I-77, I-85, and I-95;
- and Primary highways: US 29

The specific objectives of the study were:

- To determine the supply characteristics of commercial truck parking facilities along major highways in Virginia,
- To determine the demand characteristics of commercial truck parking along major highways in Virginia,
- To determine current shortfalls in the supply of commercial truck parking spaces,
- To predict demand and shortfalls for commercial truck parking in 2010 and 2020.

3 Literature Review

A detailed literature search on the relevant topics was carried out using the Transportation Research Information Service (TRIS), as well as the VTRC library, and the University of Virginia libraries. Also, an investigation into current practices for estimating parking demand on rest areas and truck stops was conducted. For current issues related to commercial parking spaces availability, an Internet search was conducted. The results of the literature review are summarized under the following four topics.

1. The relationship between motor carrier safety and the inadequacy of commercial truck parking spaces
2. Previous studies related to commercial truck parking
3. Existing methods/models for commercial truck parking demand and estimation
4. Time restriction on parking spaces in different States at rest areas

3.1 Safety and Parking

The lack of truck parking has been perceived as a safety problem for a number of years. Research by Knipling et al[13] for the National Highway Traffic Safety Administration (NHTSA) suggested that truck driver fatigue could be a contributing factor in as many as thirty to forty percent of all truck crashes. Thirty-one percent of all fatal crashes involving truck drivers were suspected to be fatigue related by the National Transportation Safety Board (NTSB) study[14] in 1990. Another NTSB study[1] in 1995 revealed that the most important causal factors for a fatigue-related are the duration of the last sleep period, the time slept in the past 24 hours, and the split sleep periods. The inadequacy of parking for commercial drivers will have an impact on all three of these factors. A 7-year study[2] on commercial motor vehicle driver fatigue and alertness by

FHWA indicated that quantity and quality of sleep obtained by the subjects in their principal sleep periods was low. The quantity and quality of sleep was listed as the third factor influencing driver fatigue and alertness after Time-of-Day of driving and duration of driving.

Truck drivers often unsafely park their trucks on the shoulders of roadways, entrance and exit ramps at interchanges, when they reach the federal Hours-of Services (HOS) limit and are unable to locate available appropriate parking spaces. Illegal parking on the shoulders of the entrance and exit ramps is hazardous for two reasons. First, the speed of the trucks as they re-renter the through lanes of the freeway from the shoulders may be significantly lower than the traffic flow on the main line because of a short acceleration distance. Second, it creates a problem for vehicles decelerating into or accelerating out of ramps. Also, it creates an additional fixed object if drivers run off the road. In 1999, a crash in Jackson, Tennessee involving four truck tractor-semi-trailers resulted in the death of two occupants of the vehicles and one seriously injured. Three of the four trucks were parked on the shoulders of the acceleration lane because the closest rest areas were full. Researchers on I-81 in Virginia also found a significant number of commercial trucks illegally parked on the ramps and access roads to parking facilities. The reason given for the illegal parking was either not finding available parking spaces or the drivers' uncertainty about where parking would be available.[12] Studies by Cheeseman et al in South Dakota and Agent et al in Kentucky have shown that risk of fatal crashes involving vehicles on shoulders are significant.[8, 9]

3.2 Previous Studies Related to Commercial Truck Parking

Many studies related to commercial truck parking were conducted throughout United States after a study was sponsored by the Minnesota Department of Transportation (MnDOT) on rest area planning. [11] This study provided a mathematical formula, based on corridor-level data collected through extensive accumulation survey at Minnesota Interstate rest areas, to estimate the required number of truck parking spaces. However, the MnDOT rest area capacity calculation formula does not consider peak nighttime commercial truck parking demand. Although the researchers mentioned that private truck stops had a notable impact on truck parking in rest areas, most studies have typically concentrated on the planning, design, operations and maintenance of rest areas.

Perfater[15] conducted a study on examination of the motorist usage and operation of Virginia's rest areas and welcome centers. Sixty nine percent of the respondents stated that rest areas were more convenient and saved time compare when asked why they would choose to stop at a rest facility rather than exit the interstate. Unfortunately, the number of commercial truck drivers asked was not documented.

In 1992, the United State Senate recommended further research on the causes of truck drivers loss of alertness at the wheel including evaluation of the adequacy of both public and private places for truck drivers to stop and rest. In 1996, this nationwide study[10] conducted by the Trucking Research Institute (TRI), Apogee Research (Apogee), and Wilbur Smith Associates (WSA) assessed the supply and demand for long-term truck parking at private truck stops at the statewide level. This study estimated a current shortfall of 28,400 public truck-parking spaces nationwide and a current short fall of 1322 truck-parking spaces was estimated for rest areas in Virginia based on their model. One disadvantage of this report was that it didn't explicitly point out where the shortfalls were and future estimation of different corridors. In the report, the researchers also suggested that some current shortfall at public rest areas might be satisfied in the future by private expansion efforts. However, they have no conclusive evidence that private truck stops and public rest areas can be directly substituted for each other.

In 1998, Section 4027 of the Transportation Equity Act for the 21st Century (TEA-21) required "the Secretary of Transportation to conduct a study to determine the location and quantity of parking facilities at commercial truck stops and travel plazas and public rest areas that could be used by motor carriers to comply with Federal hours of service rules". The survey results of this study indicated truck drivers did perceive a problem with the inadequacy of available truck parking. The analysis of the survey revealed that drivers preferred commercial truck stops and travel plazas for most activities and long-term rest, but they preferred public rest areas when stopping for a short parking. The growth rate of demand for truck parking was estimated to be 2.7 percent annually, while the growth rate of public spaces was estimated to be 1 percent annually, and the growth rate of private spaces was estimated to be 6.5 percent annually. Also a number of factors indicated that the interchangeably use of parking spaces at public rest areas and commercial truck stops and travel plazas was limited. In this study, truck parking space utilization was calculated for each state. A demand/supply ratio of 2.16 was obtained for public rest areas in Virginia, which was categorized as "shortage". The demand/supply ratio of private truck stops in Virginia was 0.8, which was categorized as "surplus". The total demand/supply ratio in Virginia was 0.93, which was categorized as "sufficient".[22] Again, the disadvantage of this report was that it didn't explicitly point out where the shortfalls were and future estimation of different corridors, which makes it difficult to take suitable actions to eliminate the shortfalls even if the results are reasonable.

The Federal Highway Administration (FHWA) hosted a Rest Area Forum in Atlanta, Georgia in 1999. The participants included seventy DOT and enforcement officials, representatives of motor carrier industry, commercial truck stop operators, commercial truck drivers, safety advocates and other interested parties. Several highest-priority recommendations related to commercial vehicle parking were listed in the final publication. During this forum, the importance of private truck stops and travel plazas for commercial vehicle parking along the National Highway System was emphasized. To encourage private enterprise, the groups suggested providing low-interest loans, public/private partnerships, tax incentives and using local law enforcement to response to crime reports at private truck stops.

3.3 Methods/Models on Parking Demand Estimation

The existing literature offers several methodologies for estimating parking demand. This includes the Institute of Transportation Engineers (ITE) parking generation rates, regression equations and cumulative distributions that are widely used in urban areas.[16] Unfortunately, the ITE rates did not cover commercial vehicle parking along major highways. In order to develop statewide rest area plans, The FHWA and several state Department of Transportation (DOTs) also developed prediction models to determine parking spaces requirement s for rest areas. These models fall into two board categories: macro-level models and micro-level models.

Macro-level models

The Minnesota DOT model was identified as a macroscopic corridor-level parking demand model for rest areas. It was incorporated in FHWA Technical Advisory T5140.8 (1979), and suggested for consideration in other states. The estimation formula used is given in Equation 3-1.

$$NTSPACES = \frac{ADT \times P \times DH \times D_t \times PF}{VHS} \tag{3-1}$$

Where:

NTSPACES = number of truck-parking spaces required,
ADT = average daily traffic with access to rest area,
P = total percentage of mainline traffic stopping at rest area,
DH = design hour usage. Design hour compares the design hourly volume, usually the 30^{th}-50^{th} highest hourly volume, to the annual ADT, producing a factor that predicts a peak usage average-hour situation,
D_t = percentage of truck-parking spaces,
PF = peak factor, ratio of average day of five summer, months to average day of year, and
VHS = vehicle parked per hour per space.

This model was reviewed by the Transportation Planning Division of the Virginia Department of Transportation (VDOT) based on a rest area usage survey in 1994. VDOT model suggested increasing the percentage of mainline traffic entering the rest area from 12 percent to 14 percent and the design hour usage ratio decreasing from 0.15 to 0.10 if the ADT exceeds 12,500 vehicles as shown in Table 3-1. The parameter values of this model were refined again by TRI, Apogee, and WSA in 1996. Recently, in a 2001 guide for development of rest areas on major arterials and freeways, the model was recommended by the American Association of State Highway and Transportation Officials (AASHTO) for use in estimating truck-parking spaces required in developing statewide rest area plans.[17]

Table 3-1 Parameters of Corridor-Level Parking Demand Model for Rest Areas

Parameter	Percent of mainline traffic entering rest area (P)	Design hour usage (DH)	Distribution between car and truck parking (D_t)	Peak factor (PF)	Vehicles per hour per parking space (VHS)
VDOT values	General, P=0.12 Welcome center, P=0.14	ADT<12,500 DH=0.15; ADT>12,500 DH=0.10	0.25	1.80	3.0

The MnDOT and VDOT models only consider the impact of traffic flow along the mainline to estimate the truck parking demand. Many other non-traffic factors, which may affect the demand for truck parking such as location, food facilities, lighting, and parking spaces available at nearby truck stops, are not considered. Only one research by Apogee Inc. developed a capacity utilization model to analyze the factors affecting truck parking at private truck stops[10]. Apogee, Inc. developed a more complicated model based on the MnDOT and VDOT models to address the impact of non-traffic factors on truck-parking demand at rest areas. The formula for the demand model is the same as that given in Equation 3-1. However, this model allows for varying the values of the parameters for the percentage of mainline traffic stopping at rest areas (P) and the design hour usage (DH), depending on a set of decision rules. These decision rules are related to the factors listed in Table 3-2. The decision rule for percent of mainline traffic entering rest area (P) allows for the increase of the default value (0.12) by 0.01 for each variable that was coded as “1” in Table 2-2. The decision rule for design hourly volume ratio (DH) is based on different ADT levels. For ADT of 12,500 and below, DH = 0.15. For ADT greater than 12,500 and less than 30,000, DH=0.10. For ADT of 30,000 and higher, DH=0.0075. Also, the recommended value for Vehicles per hour per parking space (VHS) is 2.0 instead of 3.0.

Table 3-2 Recommended Parameter Values (Source: Apogee Research)

Factor	**Data coding**
One-way average daily traffic	Enter data as collected.
Distance from the previous rest area	If distance from previous rest area exceeds 50 miles, code this variable as "1", if it does not, code it as "0"
Welcome Center	If it is a welcome center, code it as "1", if not, code it as "0".
Type of truck parking spaces at rest area	If the spaces are the diagonal pull-through type, code it as "1", if not, code it as "0".
Rest area food facilities	If food facilities are available, code it as "1", if not, code it as "0".
Rest area lighting	If the lighting is considered adequate, code it as "1", if not, code it as "0".
Availability of rest area attendant	If an attendant is available, code it as "1", if not, code it as "0"
Parking spaces at private truck stops	Enter data as collected

Although the Apogee model considered many non-traffic factors, it still did not address the impact of parking spaces at private truck stops on rest area parking needs. This model did not address the different peak periods for cars and trucks. Peak period for truck parking at rest areas in Virginia was determined from late evening to early morning, which is different from the car-parking peak period. This model did not address the impact of time restrictions on parking spaces at rest areas in different states.

Micro-level models

The Ohio DOT developed an empirical mathematical model for rest areas based on identified factors.[11] The model was a Lotus 1-2-3 spreadsheet that used the variation of traffic with time and the parking duration distribution tables to develop a daily accumulation of trucks, listed by half-hour periods, for a given rest area. Three traffic levels could be used in the model depending on the information available. They are one-way ADT only, one-way ADT and overall percentage of trucks, and one-way volume of total traffic and volume of truck from each 24 one-hour periods. The factors considered in that model included truck-parking duration, location of the rest areas, and traffic variations (total vehicles on mainline in each hour, truck percentages on mainline, and percentages of truck that entered the rest areas). The results from the model were reasonably close to the one based on survey observations, although it was sometimes below and sometimes above the survey data.

Apogee developed a capacity utilization model to examine the factors affecting truck parking at private truck stops.[10] A number of factors was considered in this model, both demand-related and supply-related. A binomial logit regression procedure was applied to estimate the capacity utilization model. Logit models are typically used in analyzing data of a qualitative nature. The procedure measured the impact of an independent variable in the model. The specified model was as follow:

$$CU=b_0 + b_1ADT + b_2EASE + b_3LRAMP + b_4DINT + b_5PRA + b_6SP + b_7TYPE + b_8Z + e_i$$

Where,

CU: utilization of private truck stop parking spaces (dummy variable equals “0” if the truck stop is not full or “1” if full or more than full)
ADT: one-way average daily traffic
EASE: the ease of entry and exit to and from the truck stop
LRAMP: the length of the ramp leading to the truck stop
DINT: the distance to a major intersection
PRA: the presence of a public rest area
SP: the total number if available parking spaces
TYPE: the type of parking space available
Z: the matrix of all the facilities provided at the rest area
b0: the constant term that captures the average effect of all omitted variables
b1…b8: the individual coefficients on the independent variables
ei: the error term

3.4 Parking Time Restriction

Virginia state law restricts parking by cars and trucks to a maximum of two hours in a rest area. Virginia is just one of many states with such a law. A 1999 survey shows that 18 States have laws restricting the amount of time that a vehicle can park in a public rest area. All east coast states in the United States except Maryland, North Carolina and New England States have certain time restrictions for parking in rest area.[1]

The opinion of the Virginia Department of Transportation is that a 2-hour parking restriction exists to provide a majority of motorists with enough spaces for the next arrivals in public rest areas; the public rest areas were designed for brief stops, not overnight parking. VDOT also stated that it had no plans to change the 2-hour restriction in public rest areas.

Several studies indicated that truck drivers preferred public rest areas for short breaks and private truck stops for extended parking.[10, 11, 12] When truck drivers are tired or out of hours-of services time to drive, they need to leave the roadway as quickly as possible. Ideally, drivers should try to plan their trips so that they can have long-term or overnight stop at private truck stops. However, the stopover is not always possible because of lack of information and no available parking spaces. Most of the researches also indicated that time restrictions for parking were incompatible with the Federal hours-of service regulations and can encourage drivers to continue driving while fatigued.[1, 2, 3, 4]

3.5 Summary of Literature Review

The literature review has identified that the lack of adequate parking spaces for commercial trucks at rest areas and truck stops was a serious problem throughout the United States. Study results have indicated that inadequacy of parking facilities for commercial trucks might be associated to fatigue-related crashes involving these vehicles. The literature review also revealed that some of the Interstate highways in Virginia were suffering from shortage of commercial truck parking spaces during late evening and early morning. While the literature review identified many studies that had investigated truck-parking demand along interstate highways, most studies focused on rest areas, which was not enough to address the problem in Virginia. Even those studies that focused on truck stops did not have detailed information on truck stops in Virginia. Further, most of the previous studies did not consider peak nighttime commercial parking demand. Another disadvantage of the previous studies was that they did not identify the specific locations of the shortfalls nor did they estimate the future shortfalls for different corridors. This makes it difficult to take suitable actions to eliminate the shortfalls. Therefore, this study was really needed to develop demand models based on extensive data collected at truck stops and rest areas in Virginia to forecast future demands at different sections of the highways.

4 Methodology

Because the methodology used in phase I of this project proved to be feasible, the methods followed in this phase II research were similar to the ones used in phase I, and consisted of the following steps:

1. Literature Review
2. Data Collection
3. Data Analysis
4. Model Testing and Development
5. Commercial Truck Parking Demand Estimation
6. Demand and Supply Comparison for Commercial Truck Parking
7. Cost Estimation for Eliminating Shortfalls

4.1 Literature Review

The literature review was conducted to identify the commercial truck parking problems and the methodology used in previous studies to address those problems. The results of this step were summarized in Chapter 3.

4.2 Data Collection

Just as it was in the phase I of this project, the extensive data collection task played a critical role in the second phase. Data collection was conducted between July 2001 and November 2002. The data collection consisted of the following tasks:

- Identification of Commercial Truck Parking Facilities
- Inventory of Each Truck Stop and Rest Area

- Observation of Commercial Truck Parking Characteristics
- Acquisition of Mainline Traffic Data
- Truck Driver and Truck Stop's Owner/Operator Survey

The problem of phase II was not the same as it was in the phase I. For example, there was no detailed traffic data on all sections of the interstate highways as was available for Interstate 81 in the phase I study. Therefore a slightly different method was used to carry out some of the tasks.

4.2.1 Identification and Inventory of Commercial Truck Parking Facilities

Researchers identified rest area locations and number by consulting with personnel of the Virginia Department of Transportation (VDOT). Rest areas in Virginia are operated 24 hours a day, and are located adjacent to the Interstate highways. Most of the rest areas provide parking spaces for passenger cars and commercial trucks, buses and leisure vehicles. All rest areas are operated free of charge to the public but have a 2-hour parking restriction. Amenities at most rest areas include rest rooms, vending machines, telephones, picnic areas, and pet rest areas. Truck stop locations were identified by two methods. First, reference documents[18,19] that listed the locations and amenities of truck stops were consulted. Additional truck stops were identified by driving along major highways, exiting at each interchange and driving at least two miles in each direction from the interchange. Truck stops are privately owned by both individuals and national or regional franchises. The majority of truck stops that serve interstate highways are located within 2 miles of an interchange on the interstate, and most operate 24 hours a day,7 days a week. Service is usually provided for all vehicle types, although emphasis is placed on services for commercial vehicle drivers. In general, the variety of services depends on the size of the truck stop.

Each rest area or truck stop with 15 or more parking spaces for commercial trucks and located within 2.0 miles from the mainlines was identified. Each site was visited and its location was recorded using GPS equipments and recorded on a Geographic Information System (GIS) map of the Commonwealth of Virginia. The detailed location information of each facility was measured from the GIS map in the laboratory, e.g. distance of the nearest upstream interchange or major intersection, distance of the nearest downstream truck stop or rest area and distance of the nearest upstream truck parking or rest area. Also during the inventory visit to each site the following specific characteristics were recorded:

- The total number of truck parking spaces available at each site
- Type of truck parking space layout
- Time of operation and limit on duration of parking, if any
- Type of ownership (private or public)
- Availability and type of food services
- Availability and type of entertainment
- Availability of other types of facilities (telephones, rest rooms, lighting)

4.2.2 Observation of Commercial Truck Parking Characteristics

In addition to the information collected during the inventory of parking areas, each selected location was visited a second time to collect data on the associated parking information including parking accumulation and duration. Some of the truck stops were visited a third time in order to obtain the maximum truck-parking accumulation. In this study, *parking accumulation* was the number of parked trucks in specific location(s) at a specified time; *parking duration* was the length of time that a truck was parked in a specific parking slot.[20] Table 4-1 showed the typical forms used to collect truck-parking information for this study. Data on each selected site was collected on one typical weekday (Tuesday, Wednesday, or Thursday). The observed data were processed in the Transportation laboratory at University of Virginia to get the numbers of trucks parked by time of day, the numbers of trucks parked in designated spaces and numbers in other spaces, and length of time each truck remained parked.

Table 4-1 Survey Form for Parking Accumulation and Duration and Sample Data

Location: *I-64 Zion Crossroads*		**Direction:** *Eastbound Exit 136*		**Date:** *August 1, Wed.*		**Prepared by** *Kate/Omar*
Spaces No.	**Time**					
	2:00 (last 3 digits of license)	**2:30** (last 3 digits of license)	**…**	**9:00** (last 3 digits of license)	**9:30** (last 3 digits of license)	**10:00** (last 3 digits of license)
1	*018*	*018*			*556*	*556*
2	*101*	*101*	*101*	*101*		*934*
3	*502*	*420*	*420*	*126*	*126*	*126*
4	*413*	*413*	*413*	*413*	*480*	*480*
5*	*Ken*	*Ken*	*Ken*		*824*	*824*
6*				*349*	*349*	*349*
…	…	…	…	…	…	…
Note: * -Unmarked						

The license plate (last three digits) method was used to collect the parking on truck stops and the data were collected every 30 minutes from 2:00pm to 10:00pm. However, one unexpected problem was found. Contrary to what was found on I-81 in the phase I study, the maximum parking accumulation at most truck stops did not occur by 10:00pm. Because of this, a supplementary survey was conducted at midnight to acquire the maximum truck-parking accumulation at truck stops and selected rest areas.

4.2.3 Mainline Traffic Data

One major difference on data collection between this phase and the first phase of the study was the availability of detailed mainline traffic data including AADT, peak hour volume, volumes on the ramps etc. This data was available from a previous study for I-81 for the phase I study, but were not available for most highways in the phase II study.

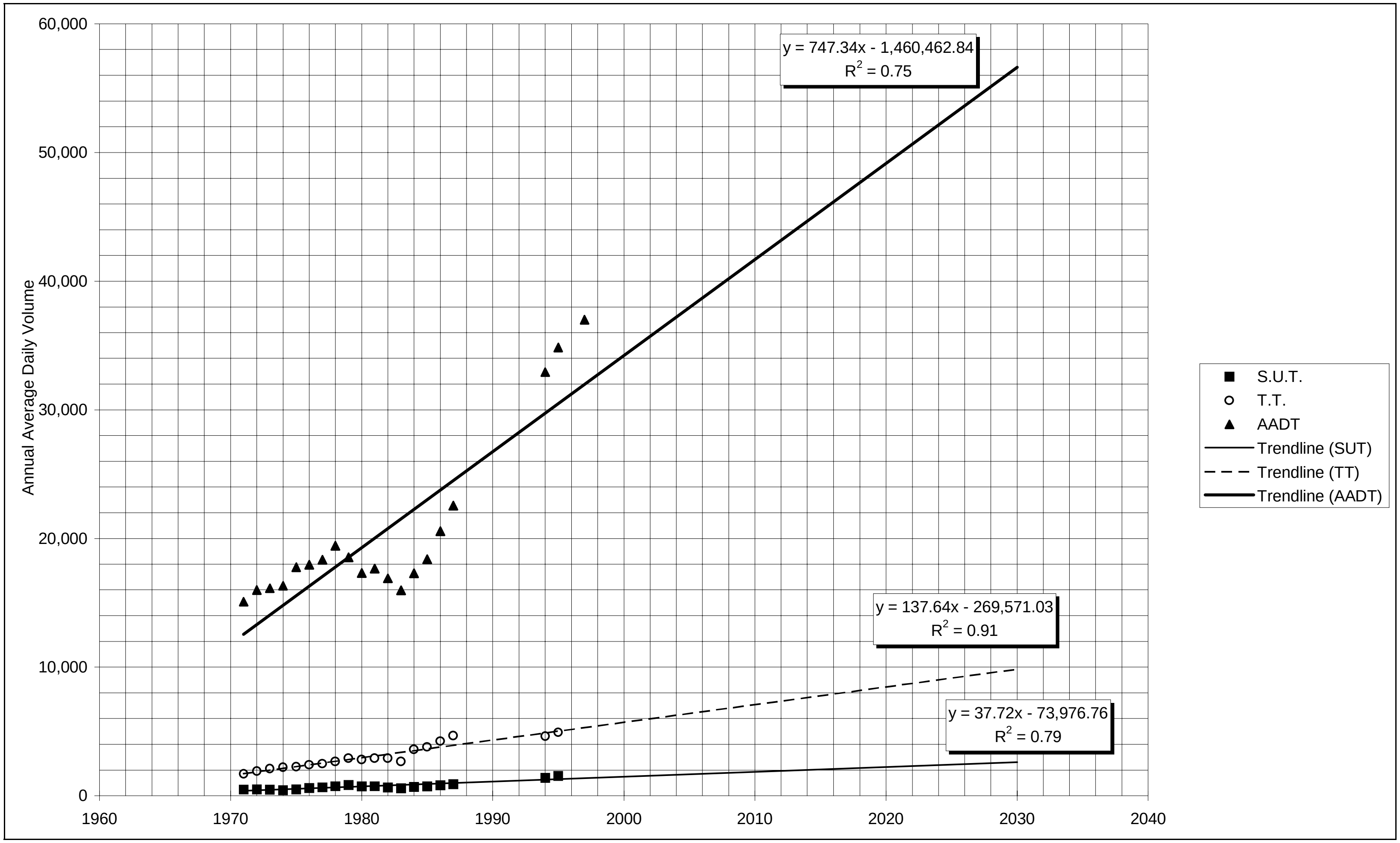
Fortunately, there is an Ethernet website managed by the Traffic Count Section of VDOT that provided detailed traffic counts information. The Traffic Count Section is managing the operation of 250 continuous count stations, including the collecting, processing, reviewing and analyzing of traffic count data, and publishing and distributing of related publications. The website is also providing traffic information for thousands of non-continuous count stations. Figure 4-1 showed the interface of traffic counts query for I-95 NB exit 89 (from MP 86.64 to MP 89.31), where there is a truck stop. The researchers could get the detailed hourly traffic counts on the time of day when they did the parking accumulation and duration survey. The continuous traffic counts included vehicle classification, and lane distribution of the traffic flow. Another important data for the mainline traffic were the growth rates of different sections along the highway corridors. For phase I of the project, the traffic growth rates were obtained from the Transportation Planning Division (TPD) of VDOT. This was because of the I-81 traffic improvement project that included the estimation of the growth rates of different section of I-81 by the TPD. However, TPD could not provide enough traffic growth rates for the second phase of the project that included other Interstate highways and one primary highway.

Erik L. Johnson, Transportation Engineer of Transportation Planning Division sent the author an Excel file used for traffic volume prediction based on historical data.

This was a linear regression model template, which was used to calculate all the traffic volume predictions for 2010 and 2020, when no growth rate available. Figure 4-2 showed regression lines for one site along I-95 within Virginia.

Figure 4-1 User Interface for VDOT Ethernet Traffic Counts Database

Figure 4-2 I-95 Application of Linear Regression Template



Note: SUT-Single Unit Truck, TT-Tractor Trailer, AADT- Average Annual Daily Traffi

4.2.4 Truck Driver and Truck Stop's Owner/Operator Survey

Questionnaire surveys were administered to truck drivers at truck stops. There was no survey form distributed in rest areas. The survey forms were left at truck stops. The investigator told some of the drivers that there were survey forms from VDOT, and asked them to pass the word around. The drivers then took the survey forms and sent them back to the investigators. Although the investigators tried to contact several trucking associations and individual truck companies, there was no response from them. Therefore, no forms were sent to them.

Information obtained from the truck drivers included frequency of use, factors that influence their selection of a particular truck stop, adequacy of existing parking facilities, and where they would park if there were no parking spaces at the rest areas and truck stops of their choice. Space was also provided for the truck drivers to record any comments they wished to convey to the researchers. The results of drivers survey in phase II were compared with those of phase I.

Truck stop's Owner/manager survey forms were left at individual truck stops and they were asked to be returned by mail to VTRC. Information obtained from the truck stop operators/managers included the day of the week and time of day that maximum accumulation occurred, the types of services provided, and the adequacy of the existing parking facilities for commercial trucks.

4.3 Data Analysis

The data on accumulation collected at each area were used to determine the variation of truck parking demand with time of day and the effect of truck traffic on the demand for parking. The data on parking duration were used to examine the length of time that trucks remained at a given site and to what extent this time was influenced by the characteristics of the site. Intervals of one half-hour were used. The information obtained from the survey of truck stop operators and drivers were also summarized to determine the specific times of a typical day truck parking facilities were full or overflowing.

4.4 Model Testing and Development

Since the researchers were not confident that the models developed in the phase I study could be directly applied to other interstate highways, these models were first tested for their applicability to each truck stop using the data on the corresponding dependent and independent variables collected during this phase II study. The Chi squared (χ^2) test at a 5% significance level was used for this analysis. Multiple linear regression analysis was used to develop new models. A correlation analysis was also conducted to test whether there was any correlation between two or more independent variables that were considered in developing the models. Variables that did not highly correlate with each other were finally used in the development of the models. The criterion was that the Pearson correlation factor between any two independent variables used in the models should be less than 0.65. It was anticipated that the independent variables that would be used in the demand model would include the following:

TotalTruck: Total number of trucks at mainline near a truck stop in half hour intervals

DailyTruck: Total number of trucks at mainline near a truck stop in a day

PercentTruck: Percent of trucks in the traffic stream in half hour intervals

Duration: Duration at a truck stop in half hour intervals

Dist_mainline: Distance from a truck stop to mainline

Dist_TS: Distance from a truck stop to the nearest truck stop

Dist_RA: Distance from a truck stop to nearest rest area

SERVICE: Dummy variable for measuring the difference of services between large and small truck stops. (Number of space>60, SERVICE=1)

In phase one, the models were developed using all of the data collected except those at two sites that were later used to test the accuracy of the models. Model 1 was based on the assumption that trucks arriving at a truck stop between 8:00P.M to 9:00P.M would stay for an average of 5 hours, trucks arriving at a truck stop after 9:00P.M would stay for an average of 6 hours; and model 2 was based on the assumption that trucks arriving after 9 P.M. would stay until 5:00 A.M. of the next day. These assumptions were based on the information obtained from truck stops' owners/managers. The results from these two assumptions did not show significant differences. In this report, a similar assumption was made.

4.5 Model Selection

Accuracy and complexity were the major considerations given in selecting the best model. The goal for selecting the best model was to select the model with the best fit and with the least complexity. There are at least two ways to consider the accuracy and complexity of the developed models.[21]

(1) *Reserve data*: Split the available data into subsets; train the candidate models on the first set, and choose the model that is most accurate over the second set. Though accurate on training data, overly complex models can estimate new points poorly.

(2) *Penalize Complexity*: This method measures the model complexity by the number of parameters, K and, using all data, choose the model that is best according to a function of K, the training error.

In this report, the first method was used to check the accuracy of the models. It is consistent with the method used in the phase I study. The Chi squared (χ^2) test at a 5% significance level is also used for this analysis.

4.6 Truck Parking Demand Estimation & Deficiency Analysis

The appropriate model was used to estimate the parking deficiencies in 2010 and 2020. It was assumed that the distributions of parking duration at the tenth and twentieth years would be the same as those currently observed. The parking demand then was determined using projected traffic volumes and truck percentages.

The increasing rates of the maximum accumulation were applied to commercial truck parking at the rest areas. It was assumed that the relationship between the parking accumulation and other variables would be the same as the current situation. The future demand was the total of the maximum accumulation for the year obtained from the model, the predicted illegal parking and the predicted legal parking at the rest areas. The difference between future demand and supply was defined as the shortage. A sensitivity test was also conducted to determine the impact of increased supply on the shortfall, by assuming that parking spaces will increase at varying annual rates.

In order to effectively compare the overall supply and demand for parking on the highways in this phase II study, each route was divided into segments of homogeneous parking segments. The major factor used to divide the road into segments was the percentage of trucks in the traffic stream from the VDOT traffic counts publication[22]. The criterion used was that each segment was selected so that the truck percentage in traffic stream of each link did not vary by more than ten percent of that for each of the other links within the segment. The start and end locations of each segment were either an interchange or a major intersection. The current deficiency in parking spaces was determined as the difference between the maximum accumulation and the number of truck parking spaces available for each road segment. Similarly, parking deficiencies in 2010 and 2020 were determined as the difference between the available parking spaces and the corresponding maximum parking demand.

4.7 Cost Estimation for Eliminating Shortfalls

While there are many factors that affect the expansion and new construction of parking spaces along the major highways, such as zoning restriction and environmental consideration, the cost for eliminating the shortfalls of commercial truck parking is a key issue for the decision makers. Unfortunately, in this phase of the study, no information was available on the cost of the recent construction of commercial truck parking facilities along the corridors. Therefore, a low-high cost analysis was used in this phase II study. According to information derived from a study[10] conducted by Trucking Research Institute (TRI), for new construction of commercial-truck parking spaces (number of spaces great than 50), the low average cost per space was about $30,000, and the high average cost per space was about $35,000. Another cost information was obtained from a real project built by Vesuvius, Inc.[23], in which the cost per parking space was estimated as $86,250 (including cost of land, evacuation cost, cost of gravel base and paving, and cost of lights and curbing). Based on the deficiencies obtained for each highway section, the minimum ($30,000) and maximum ($86,250) costs for providing the additional parking spaces to meet the future demands were then estimated.

5 Current Supply and Demand Analysis

The results of commercial truck parking supply and demand analysis in phase II study consist of parking supply characteristics and demand characteristics along major highways in Virginia, and opinions of truck drivers and truck stop owner/managers.

5.1 Commercial Truck Parking Supply Characteristics

The number of commercial truck parking spaces available at the public rest areas and private truck stops in each county along major highways in Virginia is given in Table 5-1. There are 34 counties and independent cities in the study corridors that have parking facilities for commercial trucks. Twenty-seven out of 41 rest areas and 25 out of 53 truck stops are included in this phase II study. The other rest areas and truck stops were investigated in the phase I study. Tables 5-2 and 5-3 give the name, location, and number of parking spaces for commercial trucks at each rest area and truck stop. Figure 5-1 shows the locations of the rest areas and truck stops in each county based on the GPS data. Figure 5-2 gives the clustered column for the parking spaces in truck stops and rest areas along different major highways in Virginia.

Table 5-1 Rest Areas and Truck Stops in Every County or City in Virginia

County	Rest Areas		Truck Stops	
	No.	Truck Parking Spaces	No.	Truck Parking Spaces
Phase I (Interstate 81)				
Augusta	2	28	2	117
Botetourt	1	10	2	134
Frederick	1	12	1	143
Montgomery	3	52	2	55
Pulaski	-	-	2	115
Rockbridge	1	10	6	644
Rockingham	2	37	1	69
Shenandoah	-	-	4	376
Smyth	1	8	1	30
Washington	2	110	1	35
Wythe	1	0	6	653
Subtotal	14	267	29	2371
Phase II				
Albemarle	2	33	-	-
Alleghany	2	16	-	-
Bland	2	44	1	15
Brunswick	2	26	1	25
Campbell	-	-	1	15
Caroline	2	60	4	581
Carroll	1	19	2	100
Chesapeake	-	-	1	74
Dinwiddie	2	35	2	59
Fauquier	-	-	1	50
Goochland	2	20	-	-
Greene	-	-	1	35
Greensville	1	0	2	185
Hanover	-	-	3	484
Louisa	-	-	1	44
Mecklenburg	1	25	1	85
New Kent	2 (1-closed)	59	-	-
Prince George	1	40	-	-
Prince William	6	142	-	-
Spotsylvania	1	21	1	23
Stafford	-	-	1	207
Sussex	-	-	1	90
Virginia Beach	-	-	1	205
Subtotal	27	540	25	2277
Total	**41**	**807**	**54**	**4648**

able 5-2 Rest Areas along Interstate and Primary Highways in Virginia

No.	Route	Name	Direction	Milepost	Car Spaces	Truck Spaces	Longitude	Latitude
1	I-64	Jerry's Run * [C]	EB	2	37	0	80 11 20.54	37 48 37.49
2	I-64	Longdale Furnace [T]	EB	13	0	16	79 42 45.25	37 47 48.74
3	I-64	Charlottesville East	EB	105	68	19	78 45 51.39	38 02 43.12
4	I-64	Charlottesville West	WB	113	89	14	78 37 44.25	38 02 05.04
5	I-64	Goochland West	WB	168	26	11	77 45 46.89	37 42 19.63
6	I-64	Goochland East	EB	169	26	9	77 44 57.18	37 42 00.42
7	I-64	New Kent East	EB	213	91	34	77 02 36.80	37 29 49.53
8	I-64	New Kent West	WB	213	100	25	77 02 36.63	37 29 56.10
9	I-66	Manassas East	EB	48	16	10	77 29 39.57	38 48 29.04
10	I-66	Manassas *	WB	48	17	11	77 29 38.46	38 48 32.79
11	I-77	Lambsburg *	NB	1	70	19	80 44 49.58	36 33 33.85
12	I-77	Rocky Gap North	NB	59	90	20	81 07 45.10	37 11 07.57
13	I-77	Rocky Gap *	SB	61	60	24	81 06 15.81	37 12 22.39
14	I-85	Bracey *	NB	1	96	25	78 10 47.78	36 33 11.71
15	I-85	Alberta North	NB	32	78	13	77 50 18.77	36 51 46.54
16	I-85	Alberta South	SB	32	74	13	77 50 11.79	36 51 57.94
17	I-85	Dinwiddie North	NB	55	66	15	77 29 55.40	37 06 00.97
18	I-85	Dinwiddie South	SB	55	62	20	77 29 56.07	37 06 13.14
19	I-95	Skippers * [C]	NB	1	60	0	77 34 34.28	36 32 42.86
20	I-95	Carson	NB	37	106	40	77 23 29.65	37 00 40.26
21	I-95	Ladysmith North	NB	107	100	40	77 29 31.55	37 58 37.71
22	I-95	Ladysmith South	SB	107	36	20	77 29 34.65	37 59 04.73
23	I-95	Fredericksburg *	SB	131	56	21	77 24 46.82	38 28 09.61
24	I-95	Dale City North [T]	NB	154	0	60	77 18 44.83	38 36 01.04
25	I-95	Dale City South [T]	SB	154	0	61	77 19 05.70	38 35 30.87
26	I-95	Dale City North [C]	NB	155	78	0	77 18 42.85	38 36 08.24
27	I-95	Dale City South [C]	SB	155	111	0	77 18 59.40	38 35 41.67

Note: *-Welcome Center; [C]-Car only; [T]-Truck Only

Table 5-3 Truck Stops along Interstate and Primary Highways in Virginia

No	Route	Name	Direction	Exit #	Truck Spaces	Longitude	Latitude
1	I-64	Zion Crossroads (Citgo)	EB	136	44	78 12 59.93	37 58 24.05
2	I-64	Big Charlies' 0Truck Stop	NB	282	205	76 11 11.06	36 52 59.64
3	I664	Frank's Trucking Center	EB		74	76 25 10.27	36 47 03.08
4	I-85	Simmons Bracey Travel Center	NB	4	85	78 09 10.14	36 35 57.20
5	I-85	Circle D Mart (Chevron)	SB	39	25	77 44 06.29	36 56 26.60
6	I-85	Mapco Express (East Coast)	NB	61	34	77 29 13.17	37 11 01.98
7	I-85	Thrift Mart (Exxon)	SB	63	25	77 27 59.77	37 11 50.18
8	US-29	Quarles	NB		50	77 48 01.57	38 37 50.28
9	US-29	Shell	SB		35	78 22 25.32	38 13 45.23
10	US-29	Mapco Express (East Coast)	SB		15	79 11 18.88	37 20 43.65
11	I-77	Chevron	NB	14	59	80 46 29.83	36 44 38.40
12	I-77	Exxon	SB	8	41	80 42 46.64	36 40 25.04
13	I-77	Citgo	SB	58	15	81 08 27.23	37 10 41.50
14	I-95	Simmons Travel Center	SB	8	55	77 33 25.35	36 39 38.23
15	I-95	Sadler Travel Plaza (Shell)	SB	11	130	77 33 11.84	36 42 16.67
16	I-95	Davis Truck Plaza (Chevron/Exxon)	NB	33	90	77 23 38.89	36 58 33.97
17	I-95	Richmond Travel Center (TA)	NB	89	135	77 26 52.06	37 43 30.64
18	I-95	Ashland Travel Center (TA)	SB	92	134	77 27 48.93	37 45 40.03
19	I-95	Doswell All American Travel Plaza	NB	98	215	77 27 01.69	37 50 49.78
20	I-95	Flying J Travel Plaza	SB	104	239	77 28 27.86	37 55 58.80
21	I-95	Pilot Travel Center #291	NB	104	55	77 27 56.13	37 56 16.02
22	I-95	Mr. Fuel #2	NB	104	20	77 28 01.24	37 56 23.24
23	I-95	Petro Shopping Center #56	NB	104	267	77 28 04.31	37 56 21.86
24	I-95	RaceTrac Fuel Stop	SB	126	23	77 30 07.39	38 14 00.76
25	I-95	Servicetown Travel Plaza	NB	133	207	77 29 33.42	38 20 39.55

Figure 5-1 Locations of Truck Stops and Rest Areas in Virginia

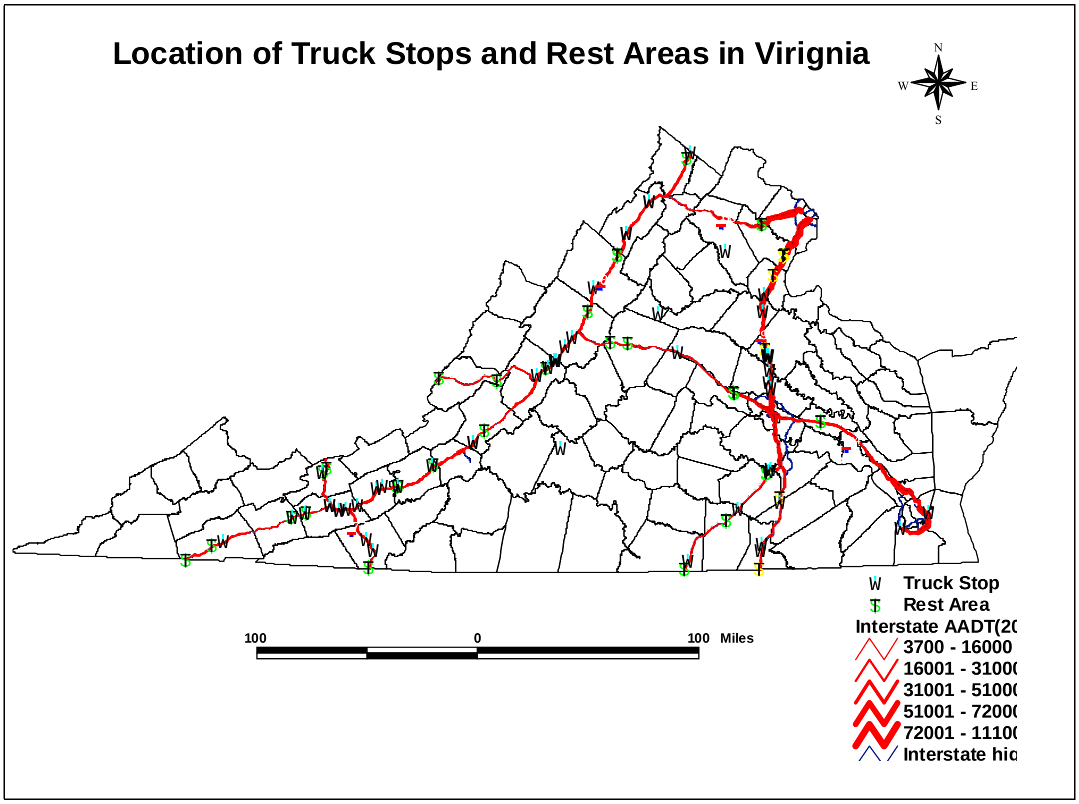
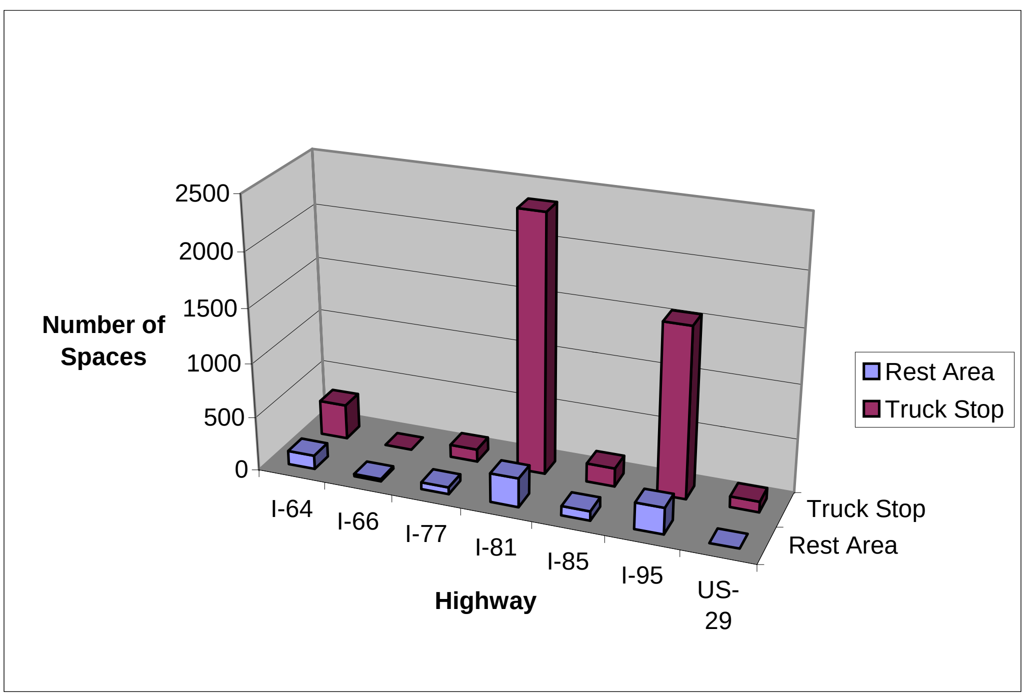


Figure 5-2 Commercial Truck Parking Spaces along Highways in Virginia



Similar to the phase I study on I-81, the parking supply pattern for commercial trucks in this phase II study showed that, the private truck stops play a major role in the provision of parking facilities for commercial vehicles within Virginia. In this phase II study, about 80% of the commercial-truck parking spaces were provided by private truck stops, while 20 % of them were provided at public rest areas. In order to effectively compare the overall supply and demand for parking on the highways later in this phase II study, each route was divided into sections of homogeneous parking segments based on the percentage of truck traffic on each route. The criterion used was that the percentage of trucks in the traffic stream on any link is not more than 10% different from that on any other link within the segment. Because truck percentages along I-95 varied much larger than on other roadways in this phase II study, the author divided I-95 so as to obtain the least variation of truck percentages within any segment while obtaining the longest length. Table 4-4 shows the different segments used. Because there are only three truck stops along US 29, and no truck stops along other primary roadways that meet the criteria for this study, the truck parking demand along US 29 was considered as a whole.

Table 5-4 Divided Segments along Interstate Highways

Section	Begin Milepost	End Milepost	Length (Mile)	Range of Truck Percentage (%)	Range of ADT (2001)
			I-64		
1	0	56	56	29-30	3700-10000
2	87	124	37	14-15	15000-20000
3	124	177	53	14	13000-23000
4	200	275	75	6-7	18000-30000
5	275	298	23	9	27000-72000
			I-66		
1	0	23	23	19-20	9700-16000
2	23	64	41	1-9	16000-97000
			I-77		
1	0	32	32	29-30	14000-21000
2	40	66	26	25-26	13000-14000
			I-85		
1	0	34	34	26-27	6900-11000
2	34	65(I-95)	31	20-22	9600-26000
			I-95		
1	0	37	37	23-26	8700-20000
2	37	65(VA 10)	28	10-19	14000-61000
3	83	133	50	16-19	34000-69000
4	133	170	37	10-12	49000-111000

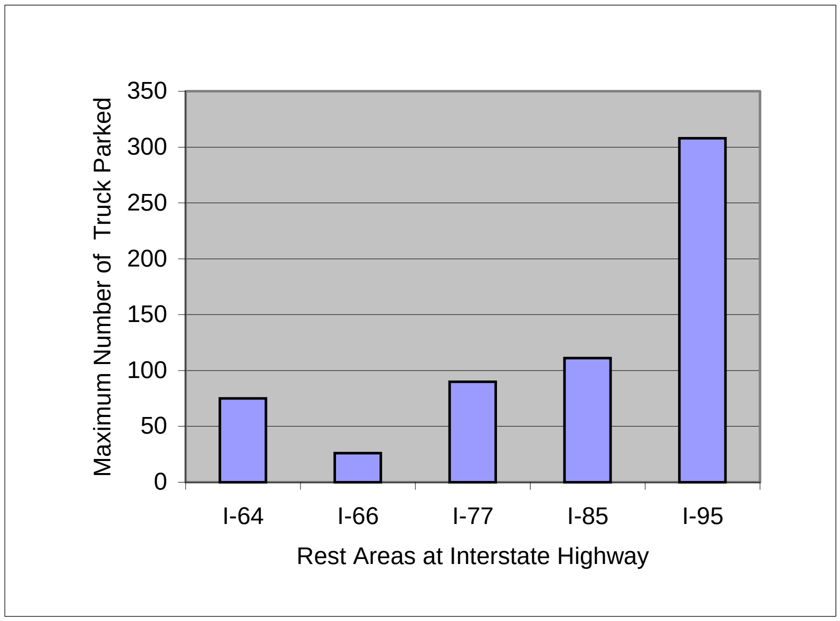
5.2 Commercial Truck Parking Demand Characteristics

In general, the demand for commercial truck parking facilities on the highways included in the phase II study were not as high as those observed on I-81 in the phase I study. The following sub-headings summarize the demand characteristics at rest areas and truck stops along different roadways in phase II.

5.2.1 Truck Parking Demand at Rest Areas

Data analysis on truck parking demand at rest areas indicated that different corridors had different patterns. Truck parking demand at rest areas along I-64 was significantly lower than those on other corridors such as I-77, I-85, and I-95. Truck parking demand at rest areas along I-66 was also different from others because of the relatively shorter average stay. The average truck parking duration along I-66 was 10~15min and no truck was parked for more than 2-hours. The average duration at rest areas along other Interstate highways was 20~60 min and about twenty-five percent of the trucks were parked for more than two hours.

Figure 5-3 Observed Maximum Truck Parking Accumulations



5.2.2 Truck Parking Demand at Truck Stops

Accumulation and duration data were obtained at twelve truck stops on the Interstate highways and one on the US-29. Truck parking demand varied among the different corridors. Parking demands at truck stops along I-95 were the highest among all the corridors, as shown in Figure 5-3. An analysis of the results of the accumulation and duration data also indicated that the variation of these characteristics during the day were similar for all truck stops except those along I-77. Both duration and accumulation tended to increase as the day went by in truck stops along I-64, I-85, I-95 and US-29, while truck parking accumulation and duration along I-77 did not have the same pattern. Possible reasons were that the truck stops along I-77 provided limited services that did not attract drivers to have long-term stay and the proximity to I-81. Figure 5-4 shows parking duration for the different times of the day at the Travel America truck stop located at exit 89 northbound of I-95. Figure 5-5 shows parking duration for the different times of the day at the Exxon truck stop located at exit 8 southbound of I-77. These two figures showed the significant difference of parking between the two truck stops.

In reviewing the results, an unexpected problem was observed in that contrary to what was found on I-81 in the phase I study, the maximum parking accumulation at most truck stops did not occur by 10:00 pm. Because of this, additional data were collected at 11 truck stops between midnight and early-morning to obtain the maximum truck-parking accumulation at the truck stops. This supplemental data gave the researchers good indications of the maximum parking accumulation. The results indicated that the parking accumulation increased with time of day along all corridors, but increased, then decreased and increased again with time of day along I-77. There were only 3 trucks parked at early morning at Exxon truck stop at exit 8 of I-77. Two other truck stops along I-77 were about half full. It showed that most of truck drivers did not want to have an over-night stay along I-77.

Figure 5-4 Accumulation vs. Time of Day at Travel America of exit 89 along I-95

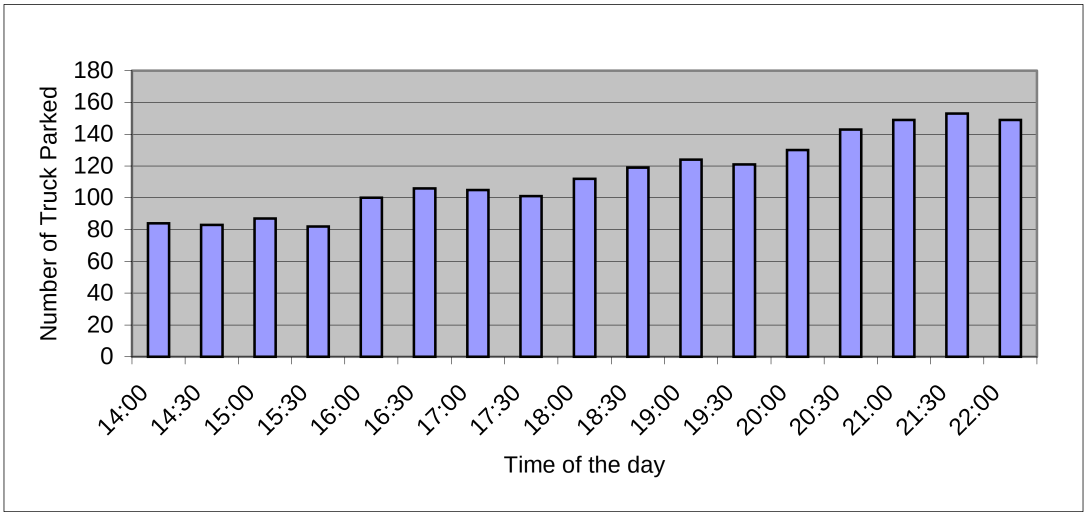
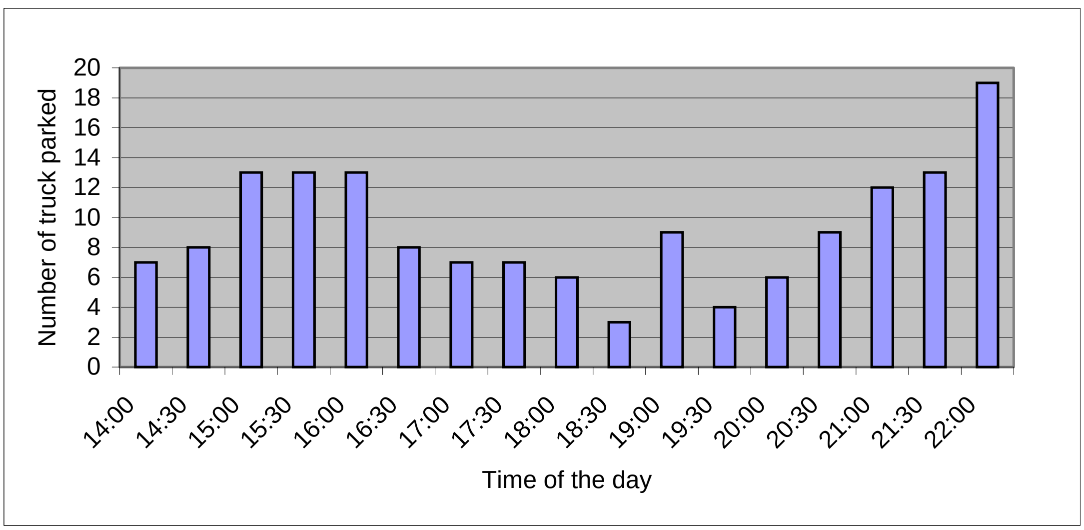


Figure 5-5 Accumulation vs. Time of Day at Exxon of exit 8 along I-77



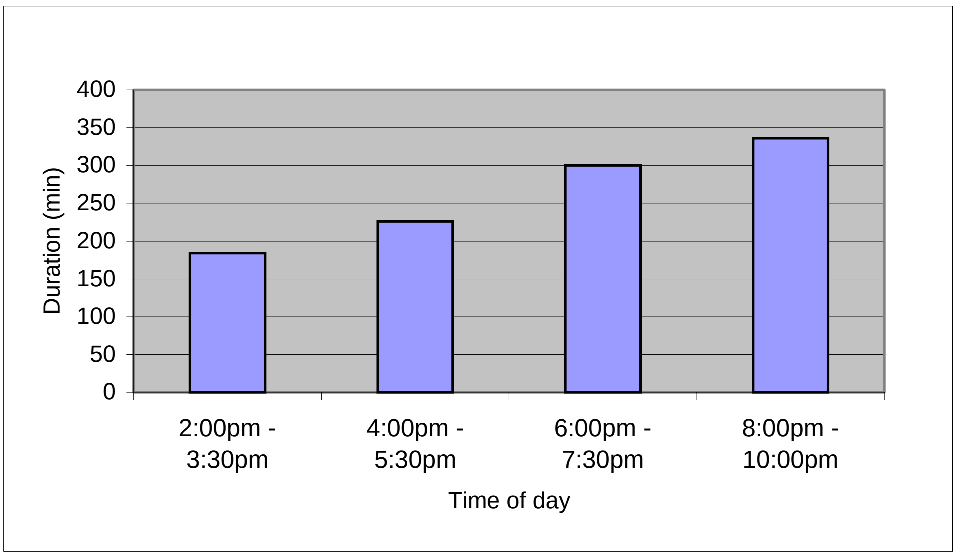
In the phase I study along I-81, two assumptions were used in developing the models with no significant difference in the results. In this phase II study, only one of the assumptions was selected as follows:

- Trucks arriving after 9 PM and not left when the survey ended would stay until 5 AM the next day.

- Trucks arriving before 9 PM and not left when the survey ended would stay for 8 hours.

This assumption was also supported by the information obtained from the truck stop managers/operators. It was also consistent with the 8-hour rest for commercial vehicle drivers in the Hour of Service regulation. This assumption was not applied to truck accumulation model on I-77 because as mentioned earlier, the segments on this route showed different characteristics. Figure 5-6 shows the average duration for different time periods at the Travel America truck stop located at exit 89 northbound of I-95.

Figure 5-6 Average Duration vs. Time of Day at Travel America of Exit 89 (I-95)



5.2.3 Illegal Parking

Unlike the phase I study, illegal truck parking was much less along all the corridors in the phase II study. There was no illegal parking on the shoulders of the roadways and ramps of the interchanges along I-64, I-77, and I-85. Illegal parking involving an average of six vehicles was observed on interchange ramps located at exits 118 and 140 along I-95.

Illegal parking on shoulders of the entrances and the exits at rest areas was very common practice. Some trucks were parked illegally while there were regular parking spaces available. One possible reason is that the drivers did not have correct information on the current availability of parking spaces, which indicates the necessity for real time information.

5.3 Current Deficiency Analysis

On the whole, the parking deficiencies observed on the highways in this phase II study are not as severe as that observed on I-81 in the phase I study.

Along I-95, the maximum demand for parking exceeded the number of available parking spaces at most truck stops by 10 to 20 percent. On average, the maximum demand at rest areas along I-95 exceeded the number of available parking spaces by about 27%. However, severe shortages of parking spaces were observed at two of the truck-only rest areas on the SB and NB of Milepost 154, where demand exceeded supply by about 47%. Several trucks were parked along the entrance and exit ramps of the rest areas. A large number of illegal parking (more than 12 trucks) was observed on the ramps of one interchange along I-95 in North Carolina, just across the Virginia/North Carolina border. This may be due to stricter enforcement in Virginia than in North Carolina.

Overall, there is no short fall of parking spaces at the truck stops on I-85. The shortfall of truck parking spaces at the rest areas along I-85 was about 10%. This has resulted in some illegal parking on entrance and exit ramps of rest areas along this route during peak demand periods.

The shortfall at the two rest areas on I-66 located at milepost 48 (EB and WB) was about twenty percent. This has resulted in the dangerous practice of trucks parking on the shoulders adjacent to these rest areas.

No parking shortfall was observed at truck stops along I-64 and I-77. The shortfall at rest areas on I-77 was about forty percent. This does not include the section of I-77 that overlaps with I-81 and included in the first phase of the study.

Table 5-5 shows the overall demand/supply ratios at rest areas and truck stops on the highways included in this phase II study.

Table 5-5 Current Truck Parking Demand/Supply Ratios along in Virginia

Demand/Supply Ratio	I-64	I-66	I-77	I-85	I-95	US-29
Rest Areas	0.78[1]	1.24	1.43	1.29	1.32	N/A [4]
Truck Stops	0.88	N/A [2]	0.50[3]	1.00	1.22	0.52 [5]

[1] EB 213 rest area at of I-64 was closed
[2] No truck stop along I-66
[3] Excluding the overlap sections with I-81
[4] No rest area along US-29
[5] Only one site was investigated

5.4 Questionnaire Survey Results

The overall response rate was about 27.4% for the driver survey forms at the truck stops. The response rate was lower than that in phase I study because most of the managers/owners of truck stops did not allow the investigators to have interviews with the truck drivers. They thought that this survey was another way that the government affected their business or the survey was a kind of solicitation. Some truck stops did not allow the investigators to give the survey forms in their properties. The response rate of the managers/owners survey was also lower than that of I-81. One perspective reason was that in the phase I study, most managers/owners knew of the planned improvement project on I-81, and they wanted to express their opinions.

5.4.1 Truck Driver Survey Analysis

The survey forms were left at several truck stops along I-77, I-85 and I-95. Forty-seven out of 150 forms were returned from truck drivers on I-95, 22 out of 75 forms were returned from I-85 and 20 out of 100 forms were returned from I-77. The vast majority of trucks were five-axle tractor-semi-trailers. More than 90% of the truck drivers did not have co-drivers. About 30% of the truck drivers were independent drivers, which was higher than that of I-81.

About 60% of drivers said there were too few parking spaces at rest areas and truck stops. About 60% of the drivers on I-95, about 60% of the drivers on I-85 and about 75% of the drivers on I-77 said that there were usually spaces available when they arrived at a specific rest area or truck stop that they planned in advance to stop at. These drivers indicated that the availability of parking spaces depended on the time of the day. Parking spaces were usually full by late evening and early morning at most truck stops.

The results also showed that no charges were imposed on truck drivers for the use of almost all of the truck stops included in this study. A few truck stops would charge a fee if drivers were not their patrons (i.e., not making use of any of the services, e.g., fuel or restaurant) or if drivers dropped their trailers overnight.

Twenty percent of the drivers indicated they would choose to stop along the roadway if they were no parking spaces available at their initial choice of rest area or truck stop.

About 80% of the truck drivers preferred to use truck stops for long rest. About 60% of the truck drivers preferred to use rest areas when they needed to take a break of less than 2 hours. This is mainly attributable to the 2-hour maximum stay restriction at Virginia rest areas.

The results of the surveys also showed that almost 100% of truck drivers were equipped with communication devices such as CB radios, cellular phones or onboard computers.

The availability of shower rooms and the location of truck stops were the most significant factors that influenced truck drivers in selecting a truck stop for either a short or a long stay. The number of parking spaces and whether parking was free were also crucial factors that influenced their decisions.

5.4.2 Truck Stop Owner/manager Survey Analysis

Thirteen out of 25 (52%) of the surveys for the truck stop owners/managers were completed and returned. The results indicated that half of the truck stop owners/managers along I-95 believed that the truck facilities were adequate Almost all the truck stop owners/managers along other routes believed that the number of truck parking spaces in their truck stops during night time were about the right number of spaces.

Most of the responding owners/managers perceived no variation in the demand of truck parking spaces among the seasons (winter, spring, summer and fall). However, they believed that there was fluctuation in the demand for truck parking spaces between daytime and nighttime.

6 Model Testing and Development

The phase I study provided two regression models on truck parking demand, which were based on parking information along I-81 in Virginia. Table 6-1 shows the coefficients of the models.[12] Although these two models gave good prediction on two validation sites along I-81, the researchers were not confident that the models could be directly applied to other interstate highways. Because there was no significant difference of the results in using the two regression models, the researchers selected one model (model 2) with more reasonable parking duration assumption for the phase II study. The model formula is shown as equation 6-1.

Table 6-1 Coefficients of Regression Models for Phase I Study

Independent Variable	Model 1	Model 2	Sign
Intercept	-1586.89036	-1475.79228	-
Percent of Truck	1.41039	1.54780	+
Parking Duration	0.1556301	0.13912	+
Total Truck Volume	0.06955	0.05898	+
Distance to I-81	-123.29288	-114.32799	-
Distance to nearest truck stop	111.95632	103.75365	+
Distance to nearest rest area	14.22398	13.80663	+
Service provided	988.99725	919.61570	+

Accumulation = -1475.79228 + 1.54780*percentTRUCK + 0.13912*Duration_2
+ 0.05898*TotalTruck - 114.32799*DIST_81 + 103.75365*DIST_TS + 13.80663*DIST_RA
+ 919.61570* SERVICE
(R^2 = 0.9294) --(Equation 6-1)

6.1 Phase I Model Testing

The model was first tested for its applicability using the data on the corresponding dependent and independent variables collected during this phase II study. The data obtained from four truck stops along I-95, two truck stops on I-85, one truck stop on I-77 and one truck stop on I-64 were used to test the applicability of the model. The Chi squared (χ^2) test at a 5% significance level was used to test the applicability of the model for the data collected from 16:00 to 22:00. The results indicated that the model could be accepted to represent the data at two truck stops on I-95, Richmond Travel Center at exit 89 and Ashland Travel Center at Exit 92. Figures 6-1 and 6-2 show the predicted parking accumulation vs. the field data for these two truck stops. Table 6-2 and 6-3 show the χ^2 test. Unfortunately, the model could not be accepted to represent the data at two other truck stops on I-95, Doswell All American Travel Center at Exit 98 and Flying J Travel Plaza at Exit 104. Figures 6-3 and 6-4 show the predicted parking accumulation vs. the field data for these two truck stops. Tables 6-4 and 6-5 show the χ^2 test results. Table 6-6 shows the test results for truck stops along I-64, I-77, and I-85. They all rejected the I-81 model.

Figure 6-1:Estimated Parking Accumulation from the Model vs. Field Data at Richmond Travel Center

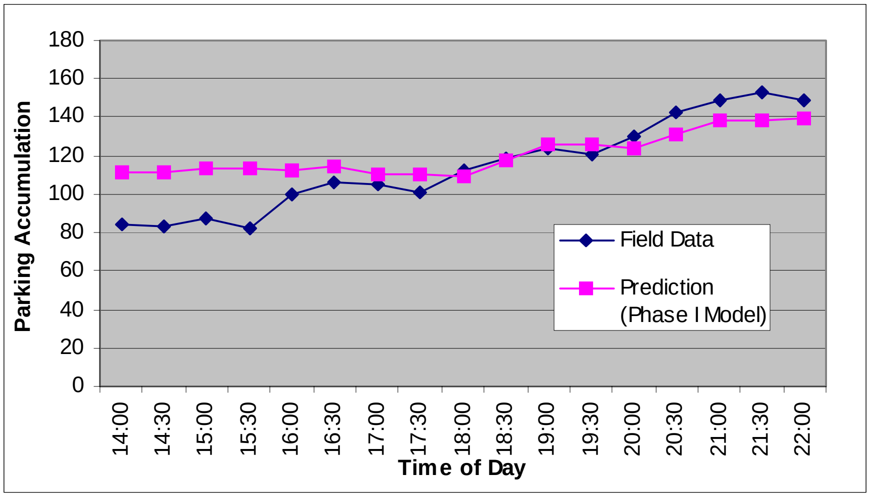


Table 6-2 χ^2 Test at Richmond Travel Center

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	100	112.7877728	-12.7877728	163.5271332	1.449865789
2	106	114.4572128	-8.4572128	71.52444834	0.624901189
3	105	110.2639228	-5.2639228	27.70888324	0.251296005
4	101	110.2639228	-9.2639228	85.82026564	0.778316819
5	112	109.1292078	2.8707922	8.241447856	0.075520092
6	119	117.3372878	1.6627122	2.76461186	0.023561239
7	124	126.2775028	-2.2775028	5.187019004	0.041076351
8	121	126.2775028	-5.2775028	27.8520358	0.220562136
9	130	124.2807528	5.7192472	32.70978853	0.263192713
10	143	131.5149928	11.4850072	131.9053904	1.002968464
11	149	137.8756378	11.1243622	123.7514344	0.897558382
12	153	137.8756378	15.1243622	228.746332	1.659077235
13	149	139.5636978	9.4363022	89.04379921	0.638015477
				TOTAL	7.925911891
Df=13-1=12	alpha=5%	Theoretical Chi-Squared=21.03		7.926<21.03	Accept it

Figure 6-2 Estimated Parking Accumulation from Model vs. Field Data at Ashland Travel Center

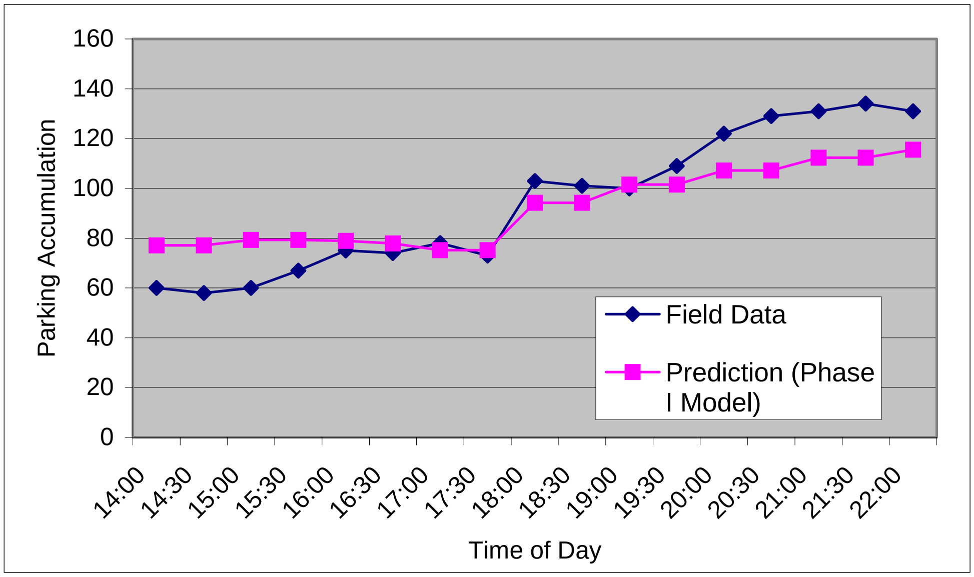


Table 6-3 χ^2 Test at Ashland Travel Center

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	75	78.8567066	-3.8567066	14.8741858	0.188622965
2	74	77.8828666	-3.8828666	15.07665303	0.193581126
3	78	75.2373766	2.7626234	7.63208805	0.101440114
4	73	75.2373766	-2.2373766	5.00585405	0.066534139
5	103	94.1534216	8.8465784	78.26194939	0.831217263
6	101	94.1534216	6.8465784	46.87563579	0.49786439
7	100	101.5458366	-1.5458366	2.389610794	0.023532336
8	109	101.5458366	7.4541634	55.56455199	0.547186904
9	122	107.1276066	14.8723934	221.1880854	2.064716019
10	129	107.1276066	21.8723934	478.401593	4.465717178
11	131	112.3092516	18.6907484	349.3440758	3.110554747
12	134	112.3092516	21.6907484	470.4885662	4.18922359
13	131	115.5451116	15.4548884	238.8535755	2.067188929
				TOTAL	18.3473797
Df=13-1=12	alpha=5%	Theoretical Chi-Squared=21.03		18.34<21.03	Accept it

Figure 6-3 Estimated Parking Accumulation from Model vs. Field Data at Doswell All American Travel Center

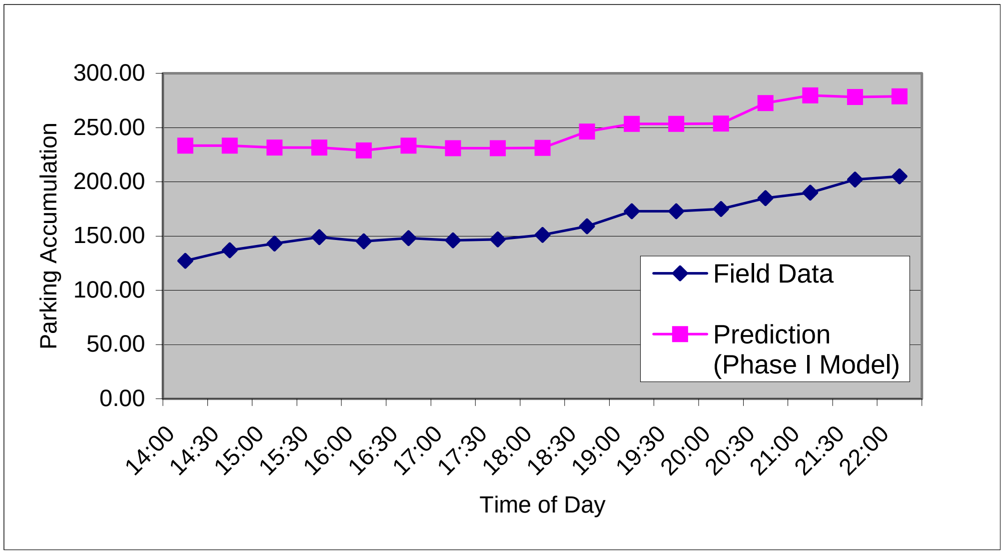


Table 6-4 χ^2 Test at Doswell All American Travel Center

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	145.00	228.9126874	-83.9126874	7041.339107	30.75993378
2	148.00	233.2254074	-85.2254074	7263.370066	31.14313379
3	146.00	230.8420274	-84.8420274	7198.169613	31.18223183
4	147.00	230.8420274	-83.8420274	7029.485559	30.4514981
5	151.00	231.1325374	-80.1325374	6421.22355	27.78156474
6	159.00	246.4357374	-87.4357374	7645.008175	31.02231947
7	173.00	253.4667574	-80.4667574	6474.899046	25.54535795
8	173.00	253.4667574	-80.4667574	6474.899046	25.54535795
9	175.00	253.7723674	-78.7723674	6205.085866	24.45138503
10	185.00	272.6926874	-87.6926874	7690.007423	28.20027004
11	190.00	279.6840974	-89.6840974	8043.237326	28.75829338
12	202.00	278.3046674	-76.3046674	5822.402267	20.92096522
13	205.00	278.6529074	-73.6529074	5424.750768	19.46777021
				TOTAL	355.2300815
Df=13-1=12	alpha=5%	Theoretical Chi-Squared=21.03		355.23<21.03	Reject it

Figure 6-4 Estimated Parking Accumulation from Model vs. Field Data at Flying J Travel Plaza

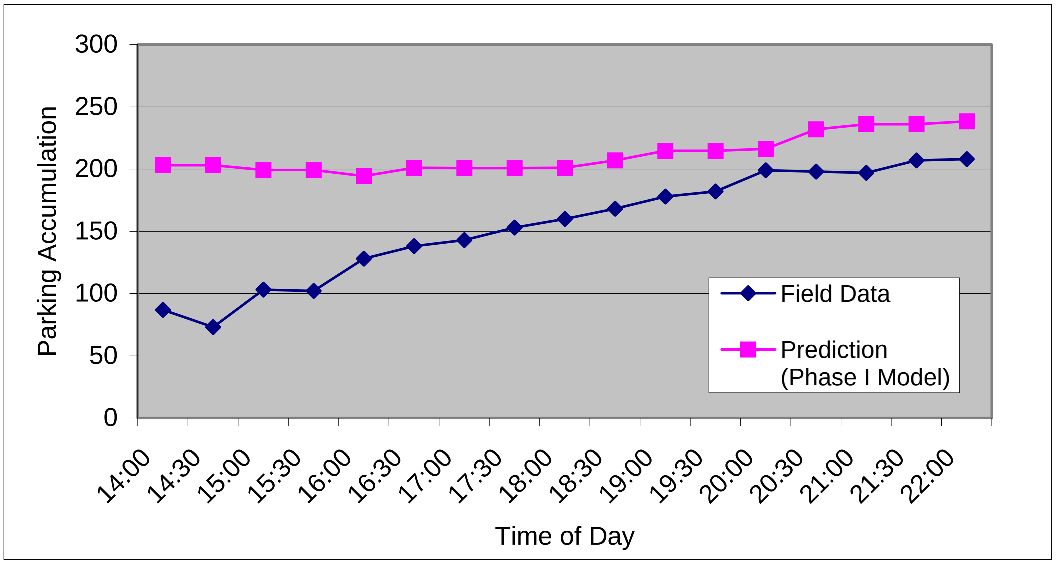


Table 6-5 χ^2 Test at Flying J Travel Plaza

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	128	194.4574402	-66.45744	4416.591358	22.71238042
2	138	200.9960802	-62.99608	3968.506121	19.74419659
3	143	200.7749452	-57.774945	3337.944293	16.62530297
4	153	200.7749452	-47.774945	2282.445389	11.36817837
5	160	201.0107452	-41.010745	1681.881222	8.367120972
6	168	206.8537852	-38.853785	1509.616624	7.297988881
7	178	214.7546077	-36.754608	1350.901187	6.290440991
8	182	214.7546077	-32.754608	1072.864326	4.995768599
9	199	216.2878152	-17.287815	298.8685544	1.381809484
10	198	231.8692552	-33.869255	1147.126448	4.947298627
11	197	235.9154602	-38.91546	1514.413043	6.419303937
12	207	235.9154602	-28.91546	836.1038386	3.544082435
13	208	238.2521152	-30.252115	915.1904741	3.841269041
				TOTAL	117.5351413
Df=13-1=12	alpha=5%	Theoretical Chi-Squared=21.03		117.53<21.03	Reject it

Table 6-6 Model Testing Results for I-64, I77 and I-85

Interstate	I-64		I-77		I-85			
Truck Stop	CITGO(Exit 136 EB)		Exxon (Exit 8 SB)		Simmons (Exit 4 NB)		Mapco (Exit 61 NB)	
Time	Field Data	Prediction	Field Data	Prediction	Field Data	Prediction	Field Data	Prediction
14:00	20	2632	7	-655	48	1696	14	960
14:30	22	2632	8	-655	36	1696	12	960
15:00	23	2627	13	-660	39	1689	12	968
15:30	21	2627	13	-660	48	1689	15	968
16:00	23	2624	13	-662	41	1699	13	958
16:30	31	2624	8	-662	40	1699	11	963
17:00	32	2621	7	-663	44	1697	9	963
17:30	26	2621	7	-663	48	1697	10	963
18:00	32	2640	6	-641	53	1702	12	961
18:30	27	2640	3	-641	52	1702	10	956
19:00	32	2642	9	-637	41	1703	10	956
19:30	29	2642	4	-637	48	1703	11	956
20:00	37	2645	6	-624	54	1713	17	956
20:30	38	2657	9	-600	56	1729	15	978
21:00	36	2650	12	-600	59	1733	13	992
21:30	39	2650	13	-600	56	1733	12	992
22:00	37	2659	19	-596	55	1742	14	996

6.2 New Models Development

The phase I model was found to be invalid at two truck stops on I-95 (Doswell All American Travel Center and Flying J Travel Plaza). However, it was recognized that truck stops along I-95 and I-81 have similar patterns. Therefore, the data sets on I-81 and I-95 excluding that for Doswell All American Travel Center, located at exit 98 on I-95, were combined together to develop a new model for these two highways. The data obtained at Doswell All American Travel Center were reserved for testing the new model as the phase I model did not adequately fit the data at this site. Another model was developed using the combined data set for I-64, I-77 and I-85, excluding the data for the Thrift Mart Truck stop at exit 63 on I-85, The two truck stops for which their data were excluded in developing the models were used for testing the applicability of the models developed. Multiple linear regression analysis was used to develop the models. Based on the lesson learned from the phase I study, the independent variables used in developing the new models included daily truck volume on mainline near a truck stop, percent of truck in half hour intervals, parking duration at truck stops, distance from a truck stop to mainline, distance from a truck stop to the nearest truck stop, distance from a truck stop to the nearest rest area, and service at truck stops.

6.2.1 Model for I-81 and I-95

The variables finally included in the new model for I-81 and I-95 are shown below together with their statistical characteristics.

Dataset Statistical Description:

Page/Date/Time	1 12-12-2002 14:51:47
Database	D:\modeldata2-95-81.S0
Dependent	ACCUMULATION

Variable	**Count**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
percentTRUCK	115	29.83652	16.70526	12.2	77
Duration	115	216.887	95.59763	42	361
DIST_mainline	115	0.3792	0.2393121	0.15	0.916
DIST_RA	115	10.61043	8.054762	1	26
Service	115	0.8260869	0.3806935	0	1
TruckVolume*DIST_TS	115	65857.35	20504.99	35980	102727.6
ACCUMULATION	115	108.2435	53.36281	10	210

Where:

percentTRUCK is percent of trucks in the traffic stream in half hour intervals
Duration is average parking duration at a truck stop at different time periods
DIST_mainline is the distance from a truck stop to mainline
DIST_RA is the distance from a truck stop to the nearest truck stop
Service is dummy variable for measuring the difference of services between large and small truck stops. (Number of space>60, Service=1; otherwise Service=0)
TruckVolume*DIST_TS is the multiplication of Daily Truck Volume and the distance to the neatest truck stop.
ACCUMMULATION is number of trucks parked in the truck stop at different time.

Results of the correlation analysis for these variables in the combined data set for I-81 and I-95 are shown in Table 6-7. These results show that all of the correlation factors were less than 0.65.

Table 6-7 Correlation Matrix of Dataset for I-81 and I-95

Pearson Correlation Factor	percentTRUCK	Duration	DIST_ML	DIST_RA	Service	TruckVolume* DIST_TS
PercentTRUCK	1	0.101298	-0.13236	-0.458637	-0.238167	-0.561572
Duration	0.1013	1	-0.01052	0.060825	0.226988	-0.07913
DIST_mainline	-0.1324	-0.01052	1	-0.353115	0.257271	0.383728
DIST_RA	-0.4586	0.060825	-0.35312	1	0.22945	-0.322359
Service	-0.2382	0.226988	0.257271	0.22945	1	-0.165063
TruckVolume*DIST_TS	-0.5616	-0.07913	0.383728	-0.322359	-0.165063	1

The parking model obtained for the combined data set for I-81 and I-95 is given as Equation 6-2:

ACCUMULATION= -217.3026+ 2.628309*percentTRUCK+ .1621317*Duration-127.4093*DIST_mainline+ 1.99189*DIST_RA+ 131.7269*Service+ 1.97887E-03* TruckVolume*DIST_TS ---(Equation 6-2)

The regression coefficients are shown as following

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95% C.L.	Standardized Coefficient
Intercept	-217.3026	26.17544	-269.1869	-165.4183	0.0000
percentTRUCK	2.628309	0.2661496	2.100755	3.155864	0.8228
Duration_2	0.1621317	2.050365E-02	0.1214899	0.2027735	0.2905
DIST_mainline	-127.4093	9.401011	-146.0437	-108.7749	-0.5714
DIST_RA	1.99189	0.4502971	1.099323	2.884457	0.3007
Service	131.7269	6.293997	119.2511	144.2027	0.9397
TruckVolume*DIST_TS	1.97887E-03	2.028141E-04	1.576857E-03	2.380883E-03	0.7604
R-Squared	0.875537				
T-Critical	1.982173				

Independent Variable	Regression Coefficient	Standard Error	T-Value (Ho: B=0)	Prob Level	Decision (5%)	Power (5%)
Intercept	-217.3026	26.17544	-8.3018	0.000000	Reject Ho	1.000000
percentTRUCK	2.628309	0.2661496	9.8753	0.000000	Reject Ho	1.000000
Duration_2	0.1621317	2.050365E-02	7.9075	0.000000	Reject Ho	1.000000
DIST_mainline	-127.4093	9.401011	-13.5527	0.000000	Reject Ho	1.000000
DIST_RA	1.99189	0.4502971	4.4235	0.000023	Reject Ho	0.992322
Service	131.7269	6.293997	20.9290	0.000000	Reject Ho	1.000000
C12	1.97887E-03	2.028141E-04	9.7571	0.000000	Reject Ho	1.000000
R-Squared	0.875537					

Model Testing: The results obtained form testing the applicability of the model at the Doswell All American Travel Center truck stop located at Exit 98 on I-95 are shown in figure 6-5. The results of the χ^2 analysis shown in Table 6-8 indicate that the model can be accepted as representing the data at this truck stop. It should be noted that as shown earlier, the phase I model could not be accepted as representing the data at this truck stop.

Figure 6-5 Estimated Parking Accumulation from Model vs. Field Data at Doswell All American Travel Center (New Model)

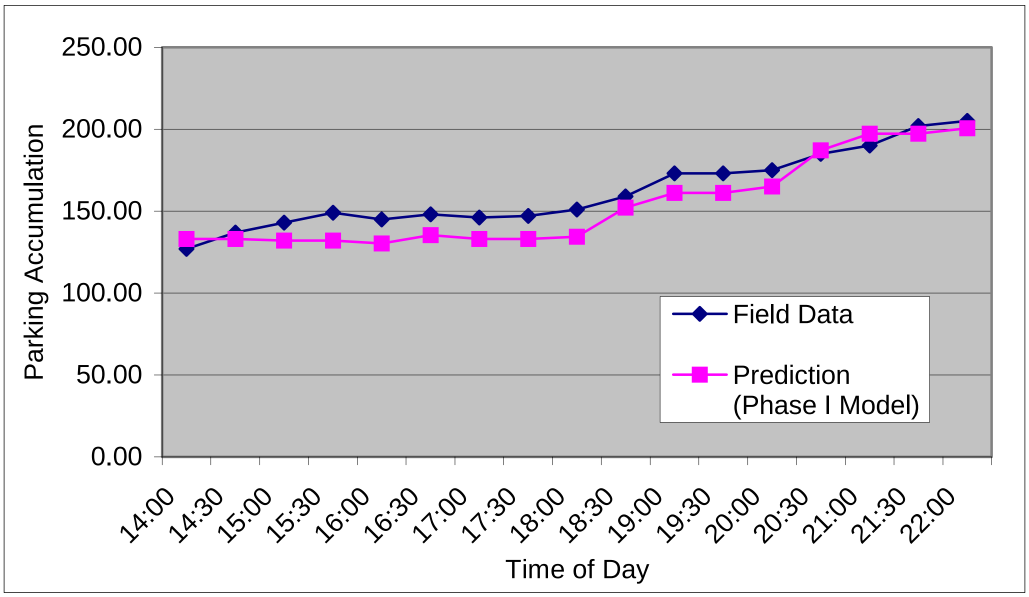


Table 6-8 χ^2 Test at Doswell All American Travel Center (New Model)

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	145.00	130.3648975	14.6351025	214.186224	1.642974666
2	148.00	135.3909802	12.6090198	158.9873793	1.17428339
3	146.00	133.0255021	12.9744979	168.3375947	1.265453556
4	147.00	133.0255021	13.9744979	195.2865904	1.468038739
5	151.00	134.3396566	16.6603434	277.5670408	2.066158629
6	159.00	152.1741436	6.82585636	46.59231502	0.306177606
7	173.00	161.1103942	11.8896058	141.3627251	0.877427715
8	173.00	161.1103942	11.8896058	141.3627251	0.877427715
9	175.00	165.0528577	9.94714226	98.9456391	0.599478497
10	185.00	187.1027689	-2.10276894	4.421637223	0.023632131
11	190.00	197.353174	-7.35317404	54.06916849	0.273971618
12	202.00	197.353174	4.64682596	21.59299148	0.109412943
13	205.00	200.5071448	4.49285516	20.18574747	0.100673457
				TOTAL	10.78511066
Df=13-1=12	Alpha=5%	Theoretical Chi-Squared=21.03		10.78<21.03	Accept it

6.2.2 Model for I-64, I-77 and I-85

The statistical characteristics of the variables in the model for the combined data set are shown below.

Dataset Statistical Description:

Page/Date/Time	1 12-13-2002 13:04:03
Database	D:\modeldata1.S0
Dependent	Accummulation

Variable	**Count**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Percent_of_Truck	72	21.56611	8.242234	12.4	52.56
Duration_1	72	175.5	88.06576	50	327
Service	72	0.25	0.4360514	0	1
TruckVolume*DIST_TS	72	83038.6	47479.47	12532.5	137741.4
Accummulation	72	26.20833	17.46702	3	77

Table 6-9 gives the correlation matrix for independent variables in the dataset for I-64, I-77 and I-85. It can be seen that all correlation factors are much below 0.5.

Table 6-9 Correlation Matrix of Dataset for I-64, I-77 and I-85

Pearson Correlation Factor	percentTRUCK	Duration	Service	TruckVolume*DIST_TS
PercentTRUCK	1	0.154689	0.181874	0.122137
Duration	0.154689	1	0.245371	0.09873
Service	0.181874	0.245371	1	0.342213
TruckVolume*DIST_TS	0.122137	0.09873	0.342213	1

The model obtained for I-64, I-77 and I-85 is given as Equation 6-3.

ACCUMULATION = -7.631802+ .2022095*Percent_of_Truck +7.625756E-02*Duration + 22.13848*Service+ 1.271871E-04* TruckVolume*DIST_TS ---Equation 6-3

The regression coefficients are shown as following

Independent Variable	Regression Coefficient	Standard Error	Lower 95% C.L.	Upper 95% C.L.	Standardized Coefficient
Intercept	-7.631802	2.611098	-12.84357	-2.420029	0.0000
Percent_of_Truck	0.2022095	9.131891E-02	1.993617E-02	0.3844828	0.0954
Duration_1	7.625756E-02	8.652085E-03	5.898793E-02	0.0935272	0.3845
Service	22.13848	1.852202	18.44147	25.8355	0.5527
C12	1.271871E-04	1.648105E-05	9.429078E-05	1.600834E-04	0.3457
R-Squared	0.881788				
T-Critical	1.996008				

Independent Variable	Regression Coefficient	Standard Error	T-Value (Ho: B=0)	Prob Level	Decision (5%)	Power (5%)
Intercept	-7.631802	2.611098	-2.9228	0.004726	Reject Ho	0.821406
Percent_of_Truck	0.2022095	9.131891E-02	2.2143	0.030213	Reject Ho	0.588072
Duration_1	7.625756E-02	8.652085E-03	8.8138	0.000000	Reject Ho	1.000000
Service	22.13848	1.852202	11.9525	0.000000	Reject Ho	1.000000
C12	1.271871E-04	1.648105E-05	7.7172	0.000000	Reject Ho	1.000000
R-Squared	0.881788					

Model Testing: Figure 6-6 shows the estimated accumulation obtained from the model and the field data. The results of the χ^2 test shown in Table 6-10 also indicate that the new model can be accepted as representing the data at the Thrift Mart Truck Stop.

Figure 6-6 Estimated Parking Accumulation Obtained from the Model vs. Field Data at Thrift Mart Truck Stop

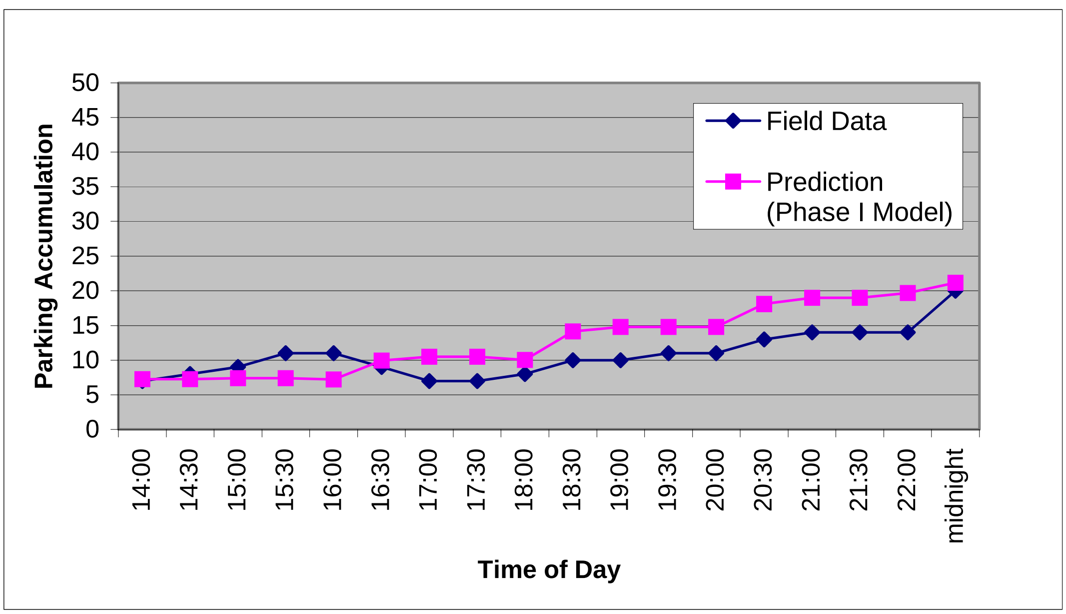


Table 6-10 χ^2 Test at Thrift Mart Truck Stop (New Model)

No	ACCU-Field data (f0)	Prediction (fe)	f0-fe	(f0-fe)*(f0-fe)	(f0-fe)*(f0-fe)/fe
1	9.00	9.965716206	-0.96571621	0.93260779	0.093581612
2	7.00	10.48943881	-3.48943881	12.17618321	1.160804065
3	7.00	10.48943881	-3.48943881	12.17618321	1.160804065
4	8.00	10.03648953	-2.03648953	4.147289609	0.413221136
5	10.00	14.15439777	-4.15439777	17.25902084	1.219339821
6	10.00	14.7893356	-4.7893356	22.9377355	1.550964568
7	11.00	14.7893356	-3.7893356	14.3590643	0.970906651
8	11.00	14.80551236	-3.80551236	14.48192433	0.978144084
9	13.00	18.08458744	-5.08458744	25.85302944	1.429561472
10	14.00	18.98441972	-4.98441972	24.8444399	1.308675233
11	14.00	18.98441972	-4.98441972	24.8444399	1.308675233
12	14.00	19.66384364	-5.66384364	32.07912473	1.63137611
13	20	21.13795089	-1.13795089	1.29493223	0.06126101
				TOTAL	13.28731506
Df=13-1=12	alpha=5%	Theoretical Chi-Squared=21.03		13.28<21.03	Accept it

6.3 Parking Demand Forecasting

In order to apply models obtained in the previous section to predict the maximum accumulation at each truck stop, the values of the independent variables in the future should be determined. However, only the future Daily Truck-Trailer Traffic (DTTT) and the Maximum Hourly Percentage of Truck Trailer (HPTT) were required, as the other variables were taken as the current values. Based on the historical data from 1997-2002, simple linear regression models for different routes were used to forecast the future daily truck-trailer traffic. Table 6-11 shows the regression models for estimating the DTTT. The future values for the Maximum Hourly Percentage of Truck were estimated using two scenarios. The first assumes that the current hourly percentages of truck on the mainline remain the same and the second assumes that they increase by 5% more than current values.

Table 6-11 Linear Regression Models for estimating the DTTT

Road	Direction	Regression Equation	R^2
I-64	EB	Y(x) = 64.89x – 127990	0.94
	WB	Y(x) = 74.17x - 146532	0.88
I-77	SB	Y(x) = 111.30x - 217119	0.80
	NB	Y(x) = 151.5x - 297340	0.85
I-85	SB	Y(x) = 90.11x - 177761	0.79
	NB	Y(x) = 38.88x – 77145	0.57
I-95	SB	Y(x) = 229.48x - 450540	0.69
	NB	Y(x) = 175.78x - 343061	0.43

Note:
general Equation: Y(x)=mx+b
Where, x = Year for projection
Y(x) = Projected Daily Truck Trailer Volume

Parking demand was forecast in several steps. First, the future maximum accumulations were determined by using the appropriate regression equation developed above. The percentage increase in accumulation between the base year and the predicted future year was then calculated. This percentage increase was then applied to the rest area accumulations to determine the estimated future accumulations. The illegal parking recorded during the data collection phase was then added to the estimated accumulation for the nearest rest area.

Unfortunately, it was not feasible to develop a separate model for US 29, the only primary highway on which a truck stop was identified. The increase on the parking demand rates on the primary highway was therefore assumed to be the same as those on I-64, I-77 and I-85. This assumption may result in some errors in estimating the future demand on US 29, but as the number of the demand for commercial truck parking on the primary highways is a very small percentage of the total commercial truck parking demand, the bias on total demand is not significant. Table 6-12 shows the results obtained for maximum accumulation at each truck stop. Table 6-13 shows the maximum accumulation at each rest area.

Table 6-12 Maximum Truck Parking Accumulation At Each Truck Stop

Route	Name	Space	Current Parking Estimation	Prediction (2010)-1*	Prediction (2010)-2**	Prediction (2020)-1*	Prediction (2020)-2**
I-64	Zion Crossroads (Citgo)	44	39	45	46	51	52
I-64	Big Charlies Truck Stop	205	182	210	214	238	242
I664	Frank's Trucking Center	74	66	76	77	86	87
I-85	Simmons Bracey Travel Center	85	59	67	68	71	72
I-85	Circle D Mart (Chevron)	25	19	22	23	24	24
I-85	Mapco Express (East Coast)	34	34	41	42	45	46
I-85	Thrift Mart (Exxon)	25	18	21	21	22	23
US-29	Quarles	50	26	30	31	33	34
US-29	Shell	35	18	21	22	23	24
US-29	Mapco Express (East Coast)	15	8	9	9	10	10
I-77	Chevron	59	26	31	32	33	34
I-77	Exxon	41	32	38	39	41	42
I-77	Citgo	15	9	10	11	11	11
I-95	Simmons Travel Center	55	70	82	86	96	101
I-95	Sadler Travel Plaza (Shell)	130	168	197	207	231	242
I-95	Davis Truck Plaza (Chevron/Exxon)	90	119	139	147	163	171
I-95	Richmond Travel Center (TA)	135	162	189	202	218	231
I-95	Ashland Travel Center (TA)	134	156	188	201	217	230
I-95	Doswell All American Travel Plaza (Texaco)	215	246	279	292	329	342
I-95	Flying J Travel Plaza	239	290	285	298	340	353
I-95	Pilot Travel Center #291	55	67	78	82	92	96
I-95	Mr. Fuel #2	20	24	28	30	33	35
I-95	Petro Shopping Center #56	267	324	379	400	445	466
I-95	RaceTrac Fuel Stop	23	28	33	34	38	40
I-95	Servicetown Travel Plaza	207	251	294	310	345	361
Total		2277	2440	2793	2926	3236	3369
Demand/ Supply			1.072	1.226	1.285	1.421	1.480

*Assuming no increase in maximum truck percentage
** Assuming an increase of 5% per annum in truck percentage

Table 6-13 Maximum Truck Parking Accumulation At Each Rest Area

Route	Direction	Mile marker	Truck Space	Current Maximum Observation	Prediction (2010)-1*	Prediction (2010)-2**	Prediction (2020)-1*	Prediction (2020)-2**
I-64	Eastbound	2	0					
I-64	Eastbound	13	16	12	14	15	16	17
I-64	Eastbound	105	19	15	17	17	19	20
I-64	Westbound	113	14	9	10	11	12	12
I-64	Westbound	168	11	9	10	11	12	12
I-64	Eastbound	169	9	10	12	12	13	13
I-64	Eastbound	213	34	Closed (26)	30	31	34	35
I-64	Westbound	213	25	18	21	21	24	24
I-66	Eastbound	48	10	16	19	19	20	21
I-66	Westbound	48	11	10	12	12	13	13
I-77	Northbound	1	19	26	31	32	33	34
I-77	Northbound	59	20	29	34	35	37	38
I-77	Southbound	61	24	35	42	43	45	46
I-85	Northbound	1	25	21	24	25	26	27
I-85	Northbound	32	13	19	22	22	24	24
I-85	Southbound	32	13	12	14	14	15	15
I-85	Northbound	55	15	16	19	19	20	20
I-85	Southbound	55	20	23	27	27	29	30
I-95	Northbound	1	0					
I-95	Northbound	37	40	34	40	42	47	49
I-95	Northbound	107	40	40	47	49	55	58
I-95	Southbound	107	20	28	33	35	38	40
I-95	Southbound	131	21	29	34	36	40	42
I-95	Northbound	154	60	93	109	115	128	134
I-95	Southbound	154	61	96	112	119	132	138
I-95	Northbound	155	0					
I-95	Southbound	155	0					
			506	600				
TOTAL			540		732	761	831	860
Demand/ Supply				1.19	1.35	1.41	1.54	1.59

*Assuming no increase in maximum truck percentage
** Assuming an increase of 5% per annum in truck percentage

Tables 6-14 and 6-15 show the estimated commercial truck parking demand for the different sections of highways for each of the two scenarios. In scenario 1, the midnight hourly truck trailer percentages are the same as current values. In scenario 2, the midnight hourly truck trailer percentages were increased by 5% more than current values.

Table 6-14 Parking Demand on Different Section of the Roadways in Scenario 1

Road	Sec.	Begin Milepost	End Milepost	Parking Spaces	Current Parking Demand	Parking Demand in 2010 (1)	Parking Demand in 2020 (1)
I-64	1	0	56	16	12	14	16
	2	87	124	33	24	27	31
	3	124	177	64	58	67	76
	4	200	275	264	200	261	296
	5	275	298	74	66	76	86
I-66	1	0	23	0	0	0	0
	2	23	64	21	26	31	33
I-77	1	0	32	119	84	100	107
	2	40	66	59	73	86	93
I-85	1	0	34	136	111	127	136
	2	34	65	119	110	130	140
I-95	1	0	37	315	391	458	537
	2	37	65	81	97	114	133
	3	83	133	1088	1296	1459	1712
	4	133	170	328	440	515	605
US29	1	Whole Route		100	52	60	66
Total				2817	3040	3525	4067

Table 6-15 Parking Demand on Different Section of the Roadways in Scenario 2

Road	Sec.	Begin Milepost	End Milepost	Parking Spaces	Current Parking Demand	Parking Demand in 2010 (2)	Parking Demand in 2020 (2)
I-64	1	0	56	16	12	15	17
	2	87	124	33	24	28	32
	3	124	177	64	58	69	77
	4	200	275	264	200	266	301
	5	275	298	74	66	77	87
I-66	1	0	23	0	0	0	0
	2	23	64	21	26	31	34
I-77	1	0	32	119	84	103	110
	2	40	66	59	73	89	95
I-85	1	0	34	136	111	130	138
	2	34	65	119	110	132	142
I-95	1	0	37	315	391	483	562
	2	37	65	81	97	120	139
	3	83	133	1088	1296	1540	1793
	4	133	170	328	440	543	633
US29	1	Whole Route		100	52	62	67
Total				2817	3040	3688	4227

6.4 Deficiency of Truck Parking Spaces

Table 6-16 shows the associated deficiencies in parking spaces for each segment of the highway system. Because the parking supply increasing rates for rest areas and truck stops are unknown, the deficiencies in table 6-16 are based on the no expansion case.

Table 6-16 Deficiency of Commercial Truck Parking Spaces

Road	Sec.	Parking Spaces	Current Deficiency	Deficiency in 2010 (1) (Low)	Deficiency in 2010 (2) (High)	Deficiency in 2020 (1) (Low)	Deficiency in 2020 (2) (High)
I-64	1	16	-4	-2	-1	0	1
	2	33	-9	-6	12	15	16
	3	64	-6	3	5	12	13
	4	264	-64	-3	2	32	37
	5	74	-8	2	3	12	13
I-66	1	0	0	0	0	0	0
	2	21	5	10	10	12	13
I-77	1	119	-35	-19	-16	-12	-9
	2	59	14	27	30	34	36
I-85	1	136	-25	-9	-6	0	2
	2	119	-9	11	13	21	23
I-95	1	315	76	143	168	222	247
	2	81	16	33	39	52	58
	3	1088	208	592	452	884	705
	4	328	112	-34	215	17	305
US29	1	100	-48	-40	-38	-34	-33
Total		2817	223	708	888	1267	1427

Because the expansion of commercial truck parking supply was unknown, this study used a sensitivity test on the results for different expansion scenarios. The sensitivity analysis tested the combinations of 1% and 2% annual truck parking spaces increase in rest areas, and 1% to 4% annual truck parking spaces increase in truck stops. For interstate 64, 77 and 85, the results indicated that if there were an annual increase of 1% in commercial truck parking spaces in rest areas and an annual increase of 1% in truck stops, the truck parking spaces deficiency for the “high” scenario in 2020 would be eliminated. Also, for Interstate 66 the results indicated that if there is an annual increase of 3% in commercial truck parking spaces in rest areas, the trucks parking spaces deficiency of the "high" scenario in 2020 would be eliminated. Also, the results indicate that there is no need to increase the parking spaces along US-29. On interstate 95, the results indicated that if there is an annual increase of 1% in commercial truck parking spaces in rest areas and an annual increase of 4% in truck stops, the trucks parking spaces deficiency of the "high" scenario in 2020 would be eliminated.

6.5 Cost Estimation

Because of the lack of recent data on construction costs for commercial truck parking facilities, the cost information used in this study was from one truck stop construction along I-81 and a study[10] done by Trucking Research Institute. The low average cost per space was about $30,000, and the high average cost per space was about $86,250 (including cost of land, evacuation cost, cost of gravel base and paving, and cost of lights and curbing). Based on the results from last section, the cost for providing the additional parking spaces to meet the future demands were then estimated and are shown in Table 6-17 and Table 6-18.

Table 6-17 Summary of Cost Estimation by Sections for Different Scenarios in 2010

Road	Sec.	Deficiency in 2010 (1)	Cost $ (Low)*	Cost $ (High)**	Deficiency in 2010 (2)	Cost $ (Low)	Cost $ (High)
I-64	1	-2	0	0	-1	0	0
	2	-6	0	0	12	360000	1035000
	3	3	90000	258750	5	150000	431250
	4	-3	0	0	2	60000	172500
	5	2	60000	172500	3	90000	258750
I-66	1	0	0	0	0	0	0
	2	10	300000	862500	10	300000	862500
I-77	1	-19	0	0	-16	0	0
	2	27	810000	2328750	30	900000	2587500
I-85	1	-9	0	0	-6	0	0
	2	11	330000	948750	13	390000	1121250
I-95	1	143	4290000	12333750	168	5040000	14490000
	2	33	990000	2846250	39	1170000	3363750
	3	592	17760000	51060000	452	13560000	38985000
	4	-34	0	0	215	6450000	18543750
US29	1	-40	0	0	-38	0	0
Total Cost			24630000	70811250		28470000	81851250

Note: * in 1996$, **in 2001$

Table 6-18 Summary of Cost Estimation by Sections for Different Scenarios in 2020

Road	Sec.	Deficiency in 2020 (1)	Cost $ (Low)*	Cost $ (High)**	Deficiency in 2020 (2)	Cost $ (Low)	Cost $ (High)
I-64	1	0	0	0	1	0	0
	2	15	450000	1293750	16	480000	1380000
	3	12	360000	1035000	13	390000	1121250
	4	32	960000	2760000	37	1110000	3191250
	5	12	360000	1035000	13	390000	1121250
I-66	1	0	0	0	0	0	0
	2	12	360000	1035000	13	390000	1121250
I-77	1	-12	0	0	-9	0	0
	2	34	1020000	2932500	36	1080000	3105000
I-85	1	0	0	0	2	60000	172500
	2	21	630000	1811250	23	690000	1983750
I-95	1	222	6660000	19147500	247	7410000	21303750
	2	52	1560000	4485000	58	1740000	5002500
	3	884	26520000	76245000	705	21150000	60806250
	4	17	510000	1466250	305	9150000	26306250
US29	1	-34	0	0	-33	0	0
Total Cost			39390000	113246250		44040000	126615000

Note: * in 1996$, **in 2001$

7 SUMMARY

7.1 Discussion

Although the scope of the project originally included only truck stops with 15 or more parking spaces, this limitation had limited effect on the results, as only a- few truck stops with fewer than 15 parking spaces existed within the 2-mile limit from highway mainline. Similarly, the restriction of considering only truck stops that were within 2 miles from the highway should have no impact on the results of the survey as commercial truck drivers indicated that they would seldom exceed that distance when looking for a parking facility. Although the data collection procedure was very time-consuming, the procedure gave the opportunity for detailed information to be obtained on commercial truck parking characteristics adjacent to highway system within Virginia.

A major problem associated with this procedure, however, was the need to obtain data on the variation in commercial truck parking (accumulation) as traffic and other independent variables vary. In this study, for example, the models were developed based on commercial truck parking accumulation in half-hour intervals, which required traffic volumes in half hour-intervals as in the phase one study. The researchers were fortunate to obtain the necessary traffic data for the phase I study because of a recent traffic study conducted on I-81 within Virginia. Similar detailed data were not available for the other highways in this phase II study. This problem was overcome by using the daily truck traffic volume in this study. The two scenarios used for the maximum percentage of trucks makes it feasible for the decision maker to select either a high or relatively lower truck percentage.

The R-squared values obtained for the models indicate that the models are good prediction tools for commercial truck parking within Virginia. This was also confirmed by the very good fit of the data at truck stops that were not used to develop the models. However, although each model closely fits the data that were not used in developing the model, there is no guarantee that the models will be suitable for parking demand forecasting at other interstate highways outside of Virginia. The reason is that parking characteristics such as parking duration and locations of the truck stops may be different.

7.2 Summary of Results

1. Currently, the demand/supply ratio for I-95 is about 1.23. The parking space shortage in rest areas along I-95 is more serious than in the truck stops. Currently, the demand of commercial truck parking at truck stops exceeds the supply by 10~20%. If no new parking spaces are provided in the future, the demand/supply ratio will increase to 1.41~1.48 in 2010 and increase to 1.65~1.73 in 2020.
2. Currently, there is no short fall of parking spaces at the truck stops on I-85. The shortfall of commercial truck parking spaces at the rest areas along I-85 is about 10%. If no new parking spaces are provided in the future, the demand/supply ratio for truck stops and rest areas combined will increase to 1.00~1.03 in 2010 and increase to 1.08~1.10 in 2020. This may result in more trucks being parked on the shoulders adjacent to the rest areas.
3. Currently, the parking spaces shortfall at the two rest areas on I-66 located at milepost 48 (EB and WB) is about 20%. It would increase to about 50% in 2010 and more than 50% in 2020.

4. Currently, no parking shortfall was observed at truck stops along I-64 and I-77. This does not include the section of I-77 and I-64 that overlaps with I-81 that were included in the first phase of the study. If no new parking spaces are provided in the future, the demand/supply ratio along I-64 will increase to 0.99~1.05 in 2010 and increase to 1.16~1.18 in 2020; the demand/supply ratio along I-77 will increase to 1.04~1.08 in 2010 and increase to 1.12~1.15 in 2020.
5. Currently, there is no commercial parking shortfall along US-29. Based on the same parking demand increasing rate on other Interstate highways, there will also have no parking shortfall in 2010 and 2020.

7.3 Comparison With Latest FHWA Study

In the latest FHWA study[22], a demand/supply ratio of 2.16 was obtained for public rest areas in Virginia, which was categorized as "shortage". This demand/supply ratio of 2.16 is much higher than the ratios obtained in this study. Although the demand/supply ratios obtained in this study for many of the rest areas are higher than 1.0, the maximum obtained was 1.43.

Similarly, the demand/supply ratio obtained in the FHWA study for private truck stops in Virginia was 0.8, which was categorized as "surplus". However, in this phase II study, the demand/ supply ratio for truck stops is 1.07. The reason for this difference may be due to an overestimation of the number of available parking spaces at truck stops in the FHWA study. During the inventory at truck stops, the investigators found that the actual existing number of spaces was less than that reported by the managers of some truck stops. Also, the size of some parking spaces was smaller than the trucks. In some cases, the type of the parking space layout also reduced the actual supply.

The information relating to Virginia provided in the FHWA study is for the whole State of Virginia, and did not provide any detailed information by highway corridors. For example, the locations of the current deficiency were not identified and no indication was given regarding the future conditions. In contrast, this study provided detailed parking demand information for different segments on Interstate corridors.

7.4 Conclusions

1. The private truck stops play a major role in providing parking facilities for commercial trucks along highway system within Virginia. Almost 80 percent of parking spaces are provided at private truck stops. Therefore, developing a short-term or long-term parking improvement plan requires the cooperation of the public and private sectors.
2. The models developed for estimating commercial truck parking demand at truck stops along Interstate highways give reasonable results.
3. The factors that affect the demand for commercial truck parking include the number and percentage of trucks in the traffic stream, the distance from a truck stop to mainline, the distance the from a truck stop to the nearest truck stop or rest area, and the facilities provided at the truck stop.
4. If the existing parking facilities for commercial trucks are not expanded, it is highly probable that this may result in more trucks being parked on the shoulders adjacent to the rest areas.

5. I-95 within Virginia will have a significant shortfall of commercial vehicle parking spaces within the next few years if no expansion to commercial truck parking facilities are undertaken.

7.5 Recommendations

The results of the study indicate the significant contribution of the private sector in providing commercial truck parking facilities in Virginia. It is therefore apparent that the construction of new commercial truck parking facilities cannot solely be undertaken by the public sector. It is recommended to conduct a study to investigate the feasibility and/or necessity of establishing a public/private partnership for the construction of new commercial truck parking facilities adjacent to interstate highways within Virginia.

The questionnaire survey indicated many truck drivers made negative comments on the questionnaire regarding the 2-hour parking limit at rest areas. It is therefore recommended to conduct a detailed study to determine the feasibility of maintaining or increasing the limit at the rest areas.

The impact of other factors, for example, commodity flow pattern and the distribution of terminals, have not been considered in developing the model. It is therefore recommended to collect such data in further research.

Although many drivers had some sort of communication devices in their trucks; it is not clear what is the best way to disseminate real time parking information on the availability of parking spaces. It is recommended that a study be conducted to determine the most appropriate technology for this. During phases I and II of this study, the practice of illegally parking commercial trucks along shoulders of the ramps at interchanges and rest areas is common. Although allowing some commercial truck parking at exit ramps may provide some temporary relief until more parking facilities are provided, this may have safety implications. Factors that should be considered include the geometry (curvature, length, width of shoulders) of the ramp, the time of day parking should be allowed, and the maximum parking duration that should be allowed. It is recommended to investigate the feasibility of allowing commercial truck parking at some interstate exit ramps.

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