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TRUCK PARKING STUDY: UNVEILING THE PARKING SPACE DENSITY AND TRUCK VOLUME RELATIONSHIP: PHASE 1

Final Report

By

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EXECUTIVE SUMMARY

Truck parking problem has been a national concern for many years due to the lack of parking space along the major freight corridors. How to assess the parking capacity adequacy remains a major challenge in addressing the provision of parking space. This study aims to reveal the relationship between the incoming truck volume and the parking capacity needed for the rest area under the hours-of-service (HOS) regulations through computer simulation.

The proposed simulation evaluates the parking capacity based on continuous trucking operations along the highway segments. The system incorporates such factors as truck volume, truck drivers' behaviors (duration of driving and time spent in the rest area), and most importantly, Hours-of-services regulations (daily driving limits). Two simulation systems are proposed, trucking on a straight highway and on a long, circular highway, respectively. A straight line simulation system uses the example of I-5 in California and test it for verification. The result corroborates the accuracy of the prediction. The second, circular system assumes continuous trucking on a closed, long enough circular highway that truck parking will eventually reach a system equilibrium. The simulation focuses on factors such as volume and travel speed of trucks and the parking density. We hope to identify potential truck parking shortage and eventually increase the trucking operational efficiency. Additional influential factors such as arriving flow, speed, rest time distribution and driving time distribution are also discussed at the end of this study, among which arriving flow is shown to have the most substantial impact.

Based on the simulation, major findings in this report include:

- The number of truck parking in a rest area, after a long time of simulation time, converges with simulation time, which indicates an equilibrium or stable parking demand.
- The number of trucks in the rest area tends to follow a particular pattern in a day without shock flow.
- The variety number of trucks in the long rest (e.g. overnight) parking is higher than that in short rest (e.g. breaks).
- Average travel speed of trucks increases with the increase in rest area density. A higher parking density enables truckers to operate closer to their full driving/working time limit.
- There appears to be a negative exponential relationship between the parking density and the number of trucks in the rest area for converged values.

The proposed simulation system would help measure the productivity of the truckers on the highway by the average travel speed over the driving and rest time. It will also assist policy makers or planners to quantify the impact of publicly provided infrastructure on the private operations. It offers an alternative way to survey, a way that is more cost efficient. This study lays a foundation for the research team to build for the phase two to develop analytical models.

1.0 INTRODUCTION

1.1 BACKGROUND

Efficient trucking contributes to American's economy success (Ernest Perry, 2017). Freight by trucks ranked the first place regarding both weight and value. The nationwide truck traffic has multiplied in the past two decades, and the growth trend will continue. Shortage of safe rest area has been a problem since the 1990s. Finding a safe and legal truck parking area when needed has been a national issue for not only commercial drivers. According to the American Transportation Research Institute's (ATRI) annual industry survey, truck parking has been a critical industry issue since 2012. Truck parking ranked third among truck drivers' most concerned issues in 2016 (Caroline Boris, 2016)

Truckers ought to obey the Hours-of-Service regulation, which requires truck drivers to rest at least 30 minutes after 8 hours and not to drive exceed 11 hours within any consecutive 24 hours of time. However, demand for commercial trucks parking has frequently exceeded the capacity, especially in the night. The shortage of parking space is obvious, depriving the right of a safe rest of many truck drivers. Policy makers and planners notice the problem as well because the shortage of suitable truck parking spaces counteracts the policy's original intention of ensuring safety by fighting fatigue. Unable to find parking spaces, truck drivers have to either park on deceleration lane of rest are or to detour, searching available spaces in the urban area. Casual parking may raise serious security issues to incoming traffic. Detouring drivers are likely to violate the regulations inadvertently.

The problem aroused both academic and industry's attention a few years ago. By 2017, at least 15 states and organizations had conduct studies on truck parking and developed trucking parking master plan for the next decades. Several modeling approaches have been put forward since the 1990s. Unfortunately, most studies stand in a macroscopic view and analysis side; little research understands the key factors contributing to the shortage or develop a quantitative method.

Current truck parking demand forecast indicates severe shortages may last over the next two decades (Wilbur Smith Associates and the Center for Transportation Research and Education, Iowa State University, 2008). The study is designed to provide a view on various factors in a quantitative approach so that to give a picture for policymakers to ease the problem. State Department of Transportation (DOT) can also make planning and programming investment decisions for their rest areas based on the method developed in the report.

1.2 HOURS-OF-SERVICE REGULATION

Motor carrier and commercial motor vehicles drivers are subject to the hours-of-service regulation. The rule is developed and enforced by the Federal Motor Carrier Safety Administration (FMCSA), Department of Transportation. The FMCSA applies to motor carriers operating in interstate commerce. The latest version was issued in 2011. Hours-of-service regulations focus on reducing the risk of fatigue driving by placing specific limits on the amount

of continuous hours and the total hours a commercial motor vehicle drivers can work on a daily and weekly basis. There are three maximum duty limits: 14-hour duty limit, 8/11 hour-driving limit and 60/70 hour duty limit. All the specific requirements can be found in the Federal Register (Department of Transportation, 2011).

1.3 STUDY PURPOSE

Truck parking has been a national concern for many years. There are several reasons behind it. One is that the deferral law regulates on-duty hours for the sake of traffic safety. Truckers cannot drive for more than 8 hours within any consecutive 24 hours of time. Truckers, especially those for inter-city travel, must find a resting spot when the driving hours reaches its enforced limit. Due to unavailability of truck parking space when it is needed, truckers are often exposed to park illegally on highway ramps or other unsafe spots. Also, driving beyond the hours limits significantly contributes to the highway fatality rate.

The objective of this study is to study the relation between truck volume and parking space density in a simulation environment as phase I. The truck space availability issue is primarily one between volume and density subject to boundary conditions. The intuitive observation is that a higher volume demands more parking space statically. The boundary condition is that there must be a minimum density no matter how low the volume is. The team believes that there must be an inherent relationship between the space needed and truck volume. Computer simulation allows the study to flexibly examine all different situations along the interstate highways in terms of volumes and density. The goal is to explore a statistical formula for this relationship in the hope that policymakers may use to examine the adequacy of truck parking space within their jurisdiction areas.

1.4 ORGANIZATION OF THE REPORT

Section two presents a literature review from both quantitative and qualitative side. The quantitative part shows a clear path for how the approach changes with time. Then a review of qualitative research is conducted, which focus on states and organizations' past research, practice and improvement.

Section three presents developed method, the related assumptions and definitions used in the simulation. Two simulation framework, straight and circular system, are designed for different purposes.

Section four shows the set-up process of the simulation and corresponding results under different scenarios. A case study was conducted on straight simulation system. The part presents corresponding affecting factors analysis. Potential solutions are put forward as well.

Section five presents conclusions and proposals for further research.

2.0 LITERATURE REVIEW

We briefly review relevant literature in this section with a focus on two specific research areas: 1) states and organizations' past research, practice and improvement, and 2) mathematic truck parking capacity estimation models.

2.1 STATE AND ORGANIZATION RESEARCH REVIEW

The demand for freight transportation by truck has grown steadily in the past few decades. It is nationally acknowledged that the shortage of safe rest area has been a problem for commercial motor drivers for a long time. The problem of truck parking has aroused policymakers' attention since the 1990s. Almost all states had conduct studies on truck parking and developed trucking parking master plan for the next decades.

Early in this century, some states have been aware the problem of truck parking shortage and researched to find solutions. The passage of Jason's Law (Section 1401(c) of MAP-21) has brought national attention to the issue of truck driver safety and required USDOT to survey each state's truck parking system. Most States have parking shortage problems, especially in Northeast and Mid-Atlantic States (Department of Transportation, 2015)

Despite some minor differences, most states apply a similar method/process to deal with the parking shortage problem. Virginia official developed a methodology to estimate the supply and demand of rest areas and truck stops along the corridor (Garber, 2002). Kansas also developed a detailed scheme for conducting survey and evaluation parking facilities and future improvement projects (Kansas Department of Transportation, 2017). Most states administration have conducted statewide freight Study to catch the freight issues and critical needs on both a statewide and regional or corridor. They also analyzed the risk and challenges related to truck parking in the State (Cambridge Systematics, 2011; School of Public Policy , George Mason University; Maryland Department of Transportation, 2016)

With a field survey and data collection, states are able to identify existing parking facilities with significant truck parking shortage issue, especially during the night peak (Pennsylvania state transportation advisory committee, 2007; Minnesota Department of Transportation, 2000; Iowa Department of Transportation , 2013; T. Adams, 2009; Chatterjee, 2010; Kansas Department of Transportation and the Kansas Turnpike Authority, 2016).The trend will continue to grow in the future (Pennsylvania state transportation advisory committee, 2007; Minnesota Department of Transportation, 2000; Minnesota Department of Transportation, 1998; Wisconsin Department of Transportation, 2014; Virginia Department of Transportation, 2011; Center for Transportation Research and Education, Iowa State University, 1999; Washington State Department of Transportation, 2016; Baltimore Metropolitan Council, 2006) . In addition, limited parking information, poor parking area design and bad weather contributed to the parking shortage as well (T. Adams, 2009). Transportation Research Board discovers several potential factors contributes to the shortfall of truck parking, including Hours of Service (HOS) regulation, continuous growth of truck transportation and increased use of tighter delivery schedules by manufacturers. For some states, lack of funding and crime reduction purpose are the two primary reason for closing public rest areas (Maryland Department of Transportation, 2016; Virginia Department of Transportation, 2011; Trombly, 2003). WSDOT identified three distinct areas of

the state with pervasive truck parking needs: metropolitan and urban areas, international and state borders and mountain passes and surrounding communities (Washington State Department of Transportation, 2016)

New Jersey, Maryland Tennessee document all commercial motor vehicles illegally parked on the shoulders and ramps on highways (Pennsylvania state transportation advisory committee, 2007; Chatterjee, 2010; Center for Transportation Research and Education, Iowa State University, 1999) . The State of Minnesota, New Jersey and Colorado (Wilbur Smith Associates and the Center for Transportation Research and Education, Iowa State University, 2008; Wisconsin Department of Transportation, 2016; Colorado department of Transportation, 2016) also build a database or inventory to record all the necessary information. In order to deal with the rapidly growing truck parking demand, state regulators proposed plenty of strategies. Virginia, Iowa, Wisconsin, developed a statewide master plan for rest area and Welcome Centers (Iowa Department of Transportation, 2013; Virginia Department of Transportation, 2011; Wisconsin Department of Transportation, 2016). Besides building new parking facilities, the strategies including cooperating with private industry (Center for Transportation Research and Education, 2010), providing accurate real-time information on truck parking availability (Kansas Department of Transportation, 2017; Iowa Department of Transportation , 2013; Washington State Department of Transportation, 2016) convert some automobile parking to truck parking (Center for Transportation Research and Education, 2010) and improving the level of service of existing parking facilities (Kansas Department of Transportation, 2017; Iowa Department of Transportation , 2013; Kansas Department of Transportation and the Kansas Turnpike Authority, 2016; Center for Transportation Research and Education, 2010). School of Public Policy at George Mason University evaluated VDOT's rest area truck parking program policy and provide recommendations, which includes consistency with Federal policy, economics, technological feasibility, enforceable, safety and community impacts (School of Public Policy , George Mason University).

2.2 MODELING REVIEW

There is limited literature focusing on developing an analytical method of truck parking problems. In 1996, FMCSA (Rest, 1996) evaluated the adequacy of rest parking facilities and regulation in 48 states along the interstates highways by observing driver's actual behaviors and interviewing industry workers. As the pioneer research into the truck parking problem, the study identified primary demand-related factors and supply-related factors based on the parking usage of the public rest areas. A linear capacity utilization model was developed and calibrated to assess the utilization and potential needs for truck parking at individual rest areas.

As the successor of the previous report, Kelley K. Pécheux, Kathryn J. Chen, et al. (Pecheux, 2002) developed analytical models to estimate the demand for truck parking spaces, which is widely used in later master plan and studies. They first assessed the current status of nationwide public rest area parking and then calibrates the truck parking demand model for a designated highway segment rather than basing the demand for parking on a single parking facility's characteristics. The model considers effects brought by seasonal, short-haul to long-haul trucking ratio and time spent at a shipper/receiver.

Similar to the United States, the European Union also suffers from the truck parking shortage problem. Florian M. Heinitz and Norman Hesse (Florian M. Heinitz, 2010) developed a demand modeling approach for limited truck parking facilities from the perspective of drivers. Different from the previous study, this study made a leap. It modeled from the standpoint of timely traffic flow instead of average daily traffic. There are also some other papers that proposed different mathematic models based on various methods, including approximate methodology (Miguel Jaller, 2013) econometric choice model (North Jersey Transportation Planning Authority, 2009), and demand modeling (Garber, 2002; M.L. Tam, 2000)

3.0 METHODOLOGY

The goal of this study is to discover the relationship between the spatiotemporal distribution of incoming truck flow and capacity utilization in the rest area under the HOS regulations. Considering both short haul and long haul demand, the study designs a straight and a circular simulation system, respectively. We input truck flow data to the system to straight roadway system to simulate the situation in the real world; with the circular system, we generate input volumes of trucks and make them continuously circulate along the large circle so that the input factors would be diminished over an extended period.

3.1 ASSUMPTIONS AND DEFINITIONS

The study develops a simulation system to discover the potential factors that will affect the number of truck parking in each rest areas on an arbitrary segment of highway. Unlike some literature that provides the annual or average seasonal number of parked trucks that have been observed, our interest is to explain the factors that determine the truck parking needs along roadways.

The study attempts to simulate long hours of driving with a large volume of trucks to observe truck parking needs. We believe 10000 hours is long enough to watch the truck parking volumes in rest areas. The length of the highway segment in the straight system can be decided according to the real situation, and the default lengthen is 1000 mile in the system.

Several assumptions and definitions are made in the simulation:

- The truck elapsed time prior to entering the studied highway segment is assumed to follow a uniform distribution. Truckers have been driving for some time before entering the highway segment. This time is referred to the elapsed time in this study. The elapsed time data is hard to collect, and little report has researched it. Therefore, at this stage of the study, we assume a uniform distribution of the driving time before entering the highway.

- Truck drivers are assumed to generally rest twice and only twice in a day cycle. First rest is a short break, then followed by a long rest to satisfy hours-of-service (HOS) regulation. We understand that this may be a restrictive assumption in many cases. However, as a start of an effort to model this quantitative relationship, this assumption is necessary. We believe, on the average, this number of rests may represent the overall picture.

- Both rest and driving durations are assumed to follow an idealized distribution. For example, the duration may follow one of the following: uniform, lognormal and normal distributing. These time data is hard to get because it not only depends on hours-of-service (HOS) regulation but also depends on drivers' preference.

- Truck speed is assumed to be a constant value. The speed refers to the uniform cruise speed and is assumed to be 65 mph, which appears to be a reasonable assumption.

- All drivers are considered to obey the hours-of-service regulation by periodically taking rests at the parking space.
- Service time for loading/unloading is not considered in the simulation.

All denotations and definitions are summarized in Table 1. The uppercase symbol represents the time data, in the format of the Hour: Minute: Second; the lowercase refers to numbers, such as the length of time, distance to start point. Notation with a combination of the two denotes constant values in the regulation.

Table 1: Truck Simulation Parameters and Definitions

Property	Denotation	Definition
Elapsed time	t_e	Elapsed driving time before entering the highway section
Start time	T_s	Time entering the studied highway section
Short rest duration	r_s	Rest length after a maximum of 8 hours' driving
Long rest duration	r_l	Rest length after the driving reaches the 11 hours' driving limit in a consecutive 24 hours
First driving time	d_1	Driving time after entering the highway but before taking the short rest
Second driving time	d_2	Driving time after taking the short rest but before taking the long rest
Short rest breakpoint	B_S	The time when the truck driver begins to take the short rest, either voluntarily or under HOS requirement
Long rest breakpoint	B_L	The time when the truck driver begins to take the long rest, either voluntarily or under HOS requirement
Speed	v	Average cruise speed in the highway section
First legal driving time	t_1	Maximum legal driving time left before taking a mandatory short rest
Second legal driving time	t_2	Maximum legal driving time left before reaching maximum driving hours limit
Max driving time short	$MaxWS$	Max driving hour until a mandatory short rest
Max driving time long	$MaxLS$	Max driving hour until a mandatory short rest
Rest area number	c	The rest area number where the driver takes a rest
Rest area location	l_c	The rest area c's location, measuring by the distance from the start point.
Enter location	l_e	Location where the truck enters the highway section
Exit location	l_x	Location where the truck leaves the highway section

3.2 INPUT DATA

The system takes the following data as inputs: elapsed time, start time, short and long rest duration, first and second driving time, speed, entry and exit location. These inputs can be divided into three categories based on their sources: necessary information, actual data, and estimated data. Necessary information refers to elements that can constitute the highway segment, including the length, location information of entrance, exit and rest areas.

Actual data always comes from the real world, including real-time data and historical data. Such as the start time, short and long rest duration. For accurate prediction, the truck data such as

traffic flow, rest durations, etc. can be derived using trucking data at an observation point such as entrance and exit points into the highway section and the rest areas respectively. Actual data such as the number of trucks passed by a monitoring point at each time during the day may be used to facilitate the estimation of probability distributions, which is often available from the state monitoring system posted on state DOT's websites.

When real-world data is hard to get, estimated data can be a used as inputs. These data are generated from estimated distributions. There is barely statistics result of, for example, the elapsed time. However, reasonable distribution can be assumed. The estimated data comes from the assumed distribution. For each simulation, elapsed time, start time, first and second driving time, short and long rest duration, are generated by specific distributions. For example, the time of entry into the highway section can be obtained by directly borrowing historical data. When the data is not available, the data can be generated through a truck flow function. The truck flow (volume) function may be obtained in literature or by matching the historical data with probability functions regarding truck headway or other parameters. Random numbers can be generated and used according to the flow distribution regarding such parameters as mentioned above.

3.3 STRAIGHT HIGHWAY FRAMEWORK

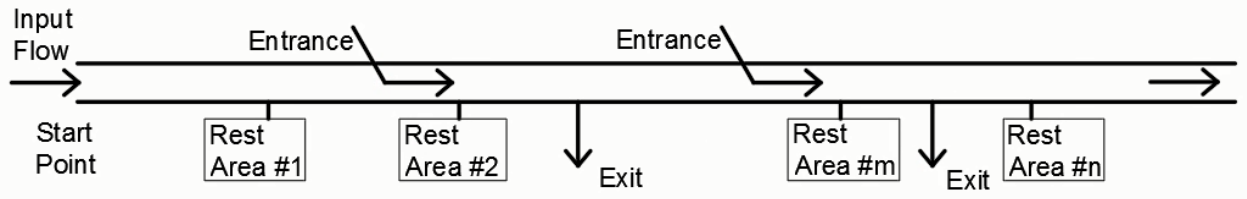

Figure 1: Basic structure of the straight highway simulation system

The first case is on a straight highway section. The system is designed to simulate the behavior of trucks on the interstate. The section length for straight simulation system is currently set at 500 miles, and it can be changed to different numbers. The location of each rest area can be input as it is in a real situation. By default, there is no entrance or exit on the highway section between two consecutive rest areas in one direction, but note that the spacing of rest areas may also be changed as needed in the simulation. In addition, truck flow is input at each entrance and exit. The system records all the information of trucks during the simulation, including time of entry into the highway section, first and second driving time length, time entry and leaving the rest area, short and long rest duration. The adoption of the straight line highway is also useful to test the turbulence of incoming traffic flow to the parking system.

3.4 CIRCULAR HIGHWAY FRAMEWORK

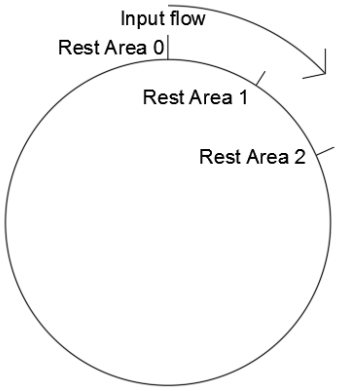

Figure 2: Basic structure of the circular highway simulation system

One disadvantage of the straight roadway is that input data such as arriving truck flow cause a bias in the final results. The second case is on a circular road to overcome the shortcomings of a deterministic distribution of flow input in the case of a straight road as studied in the first case. The system is a 1000 mile circle without any entrance or exit, which we believe long enough to examine the equilibrium. Equilibrium is one in which a specific flow of trucks on this circular highway reach a stable state of rest area capacity density to satisfy the truck parking need. In this simulation, the default truck speed is set to be 65 mph, which is mainly considered to be the average cruise speed on the highway. All other parameters and generated data are set to be the same as on the straight line simulation. A daily flow will be released at the beginning of the simulation. Traffic is continuously generated, and input to the circular roadway until a certain number of trucks are in the system. The basic structure of the circular simulation system is shown in Figure 2. The number of cycles to run in the simulation system is set to be 10000. In the circular simulation, variables are limited and the time length for the input traffic flow data is limited to a certain time range. The simulated trucks will go through the driving-rest cycle. The maximum time length of input flow is a restraint to be time that truck runs one cycle length without stopping.

4.0 SIMULATION

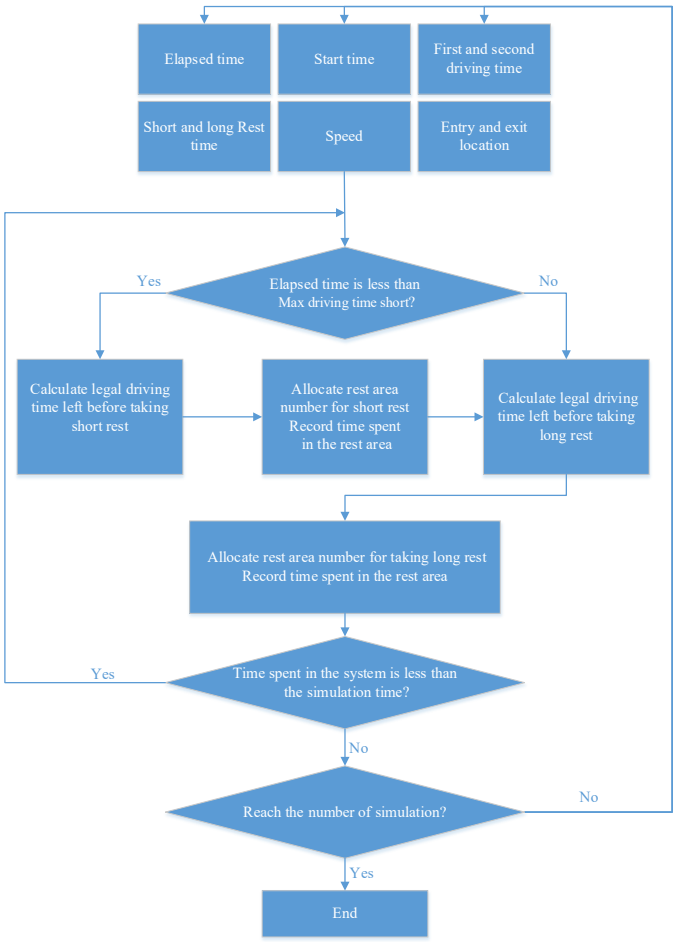

Figure 3: Simulation flow chart for a typical cycle

Figure 3 shows the detail steps. After entering the data, the system will examine the elapsed time (t_e), if it is greater than max driving time short, based on Hours-of-service (HOS) regulation, $MaxWS$, it implies that the truck has taken short rest before entering the highway segment. Thus the system will directly go to the second phase calculation. Otherwise, the system will calculate the first legal driving time t_1, which is obtained by deducting the driving time that the driver has experienced from a max driving time short, $MaxWS$, and then compare it with the generated first driving time length. The smaller value will be saved as d_1 based on the assumption that all drivers follow the rules. The driving time will be used to choose the rest area and will be modified to first and second driving time accordingly based on the location of taking rest later. They can be expressed by the following equations:

$$\boldsymbol{t_1 = MaxWS - t_e} \quad (1)$$

$$\boldsymbol{d_1 = \min(t_1, m_1)} \quad (2)$$

Where m_1 are generated driving time from $N_1(\mu_1, {\sigma_1}^2)$;

4.1 SIMULATION PROCESS

After the determination of the legal driving time length, the initial time point for short rest is determined accordingly. In most cases, it is almost impossible to have a parking lot right at the place where the truck driver arrives when he reaches the upper limit. For example, a driver is at the rest area i and can drive 8 hours legally after a qualified long rest. However, after 8 hours' driving, there is less likely to be a rest area at the place he reaches. In addition, the driver can take a short rest for other reasons as well. Therefore, the truck should be allocated to the nearest rest area where it can reach without violating the Hours-of-service regulation. After 8 hours of driving, if he has passed No. j rest area but there is still some distance to reach No. $(j+1)$ rest area, the simulation system will allocate the truck to rest area No. j. In general, the system will first determine the remaining legal driving distance. The number of rest area a, for taking rest can be decided by the following equation:

$$\boldsymbol{c = \arg_j \min\left(v \times l_k + l_i - l_j \right)\ i, j = 1, 2 \ldots n} \tag{3}$$

With $v \times l_k + l_i - l_j \geq 0$, n is the total number of rest area;

After determination of location to take a rest, the driving time can be modified correspondingly by the following equations:

$$\boldsymbol{d_1 = \frac{l_{c_1} - l_i}{v}} \tag{4}$$

Similar to the determination of driving time, rest time for a truck driver is random and hard to determine. Both of them are assumed to follow a normal distribution in the simulation system. In the future, the distribution can be generated using the real data from the industry. For example, data acquired from the rest area monitoring system.

For the second driving time, or driving time after short rest, the system similarly takes data, calculating the second legal driving time t_2 by deducting elapsed time from the max driving time long, $MaxLS$, comparing it with second legal driving time length, $MaxLS$ and save it as t_2. Then the rest area where the driver takes long rest and corresponding driving time can be determined accordingly.

$$\boldsymbol{t_2 = MaxLS - t_e - d_1} \tag{5}$$

$$\boldsymbol{d_2 = \frac{l_{c_2} - l_j}{v}} \tag{6}$$

After determination of the two driving time, it is easy to get the schedule of a truck driver in a day cycle, which is shown in Table 2. The simulation system records all the generated information.

Table 2: One typical cycle for a truck driver in the simulation

Start time	Short rest breakpoint (B_S)	Short rest end	Long rest breakpoint (B_L)	Long rest end (start time of the next cycle)
T_s	$T_s + d_1$	$B_S + r_s$	$B_S + r_s + d_2$	$B_L + r_l$

In straight highway system, if a truck in the simulation system finishes a day cycle before simulation time running out, the left time will be examined to check whether the truck will be still in the observed highway section. If the truck will drive out the section before taking the short rest, the system will not calculate to save computing power because the purpose is to get the number of trucks in a rest area. Usually, each truck point will only go through the steps once, but it happens that the truck will take another short rest in the observed highway section during the simulation period. Under the situation, the truck will go through another cycle in the chart. In the circular highway system, the truck will go through the cycles until a certain number is reached.

4.2 SIMULATION SET UP

Two models are developed. One is for a straight one-way highway section, which tries to simulate the real behavior of trucks on the interstate. As an initial condition, the section length for straight simulation system is 500 mile. It can be changed accordingly based on the project situation. There are 20 consecutive parking facilities and can be added more as needed. The location of each rest area can be input as it is in the real condition. By default, there is no entrance or exit on the highway section, but they can be added as needed of simulation. Also, truck flow is needed as an input at each entry and exit. The distribution in the straight simulation are summarized in Table 3.

Table 3: Distribution Used in the Simulation

Property	Distribution used
Elapsed time	Uniform distribution $U_1(a_1, b_1)$
First driving time	Normal distribution $N_1(\mu_1, {\sigma_1}^2)$
Second driving time	Normal distribution $N_2(\mu_2, {\sigma_2}^2)$
Short rest duration	Lognormal distribution $lgn(\nu, \rho^2)$
Long rest duration	Uniform distribution $U_2(a_2, b_2)$

The other one is a circular highway. An initial truck flow pattern in a day is input to the system. Trucks are kept in the system and rest as needed under the Hours-of-service (HOS) regulation. The purpose is to see whether the number of trucks in the parking area will converge to a particular value as time goes by. The second model can also be used to find the relationship between truck flow pattern and parking density. Each cell represents one truck. For the rest area properties, the system stores the id number, location, number of trucks that are in short and long rest, respectively, during each hour.

4.3 CASE STUDY OF THE STRAIGHT SYSTEM

For verifying the effectiveness of the simulation for truck parking, an actual highway segment, California Interstate 5 northbound (I-5N), is used as a case study. Further, a conceptual implementation is generalized to quantify the effectiveness of the proposed simulation and productivity of drivers.

I-5N is one of the major interstate highways that runs south to north along the west coast. The segment of I-5N in California in this case study is about 500-miles long, with five public rest areas from San Diego to Sacramento as illustrated in Figure 3. Counting from the southern beginning of I-5N, the rest areas involved are Aliso Creek, Lebec, Buttonwillow, Coalinga/Avenal, John "Chuck" Erreca, and Westley. The truck flow along the I-5N segment, and estimated truck parking amount in the rest areas are provided by detector stations from Caltrans Performance Measurement System (PeMS) (21).

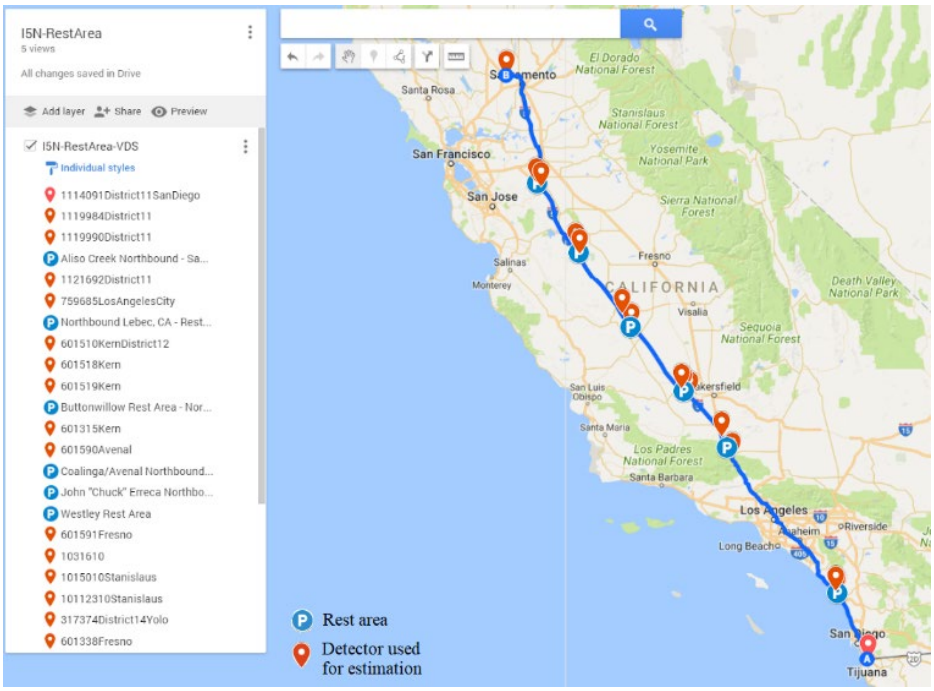

Figure 4: Five rest areas over test segment on I-5 N in California

The detector stations spread out on I-5N. The point readings in actual detectors are aggregated every 33-mile along the I-5N as inputs for the simulation. Based on the aggregated truck flow readings from the stations, the parameters implemented in the simulation system are calibrated and tabulated in Table 4.

Table 4: Parameters Used in the Simulation

Parameter	a_1	b_1	μ_1	σ_1	μ_2
Value	0.5	7.5	7.5	0.8	3
Parameter	σ_2	ν	ρ	a_2	b_2
Value	1.2	0.1	0.2	10	15

The simulation proposed predicts the amount of truck parked at each rest area point and the predicted results are compared with estimated point readings. The estimated point readings are approximated from the inflow and outflow of the nearest detector stations to each rest area. The subtraction is based on inflow and outflow per hour. Hence, if trucks entering and exiting the parking area happen to be within an hour, they will appear on both detector readings. They will be void after subtraction. Through the comparisons, potential sources of errors from the estimated point readings and simplifications or assumption made of the proposed simulation may cause the differences in the output comparisons.

PeMS is the widely used open access freeway data source. The argument of accuracy in terms of the detector is always a topic. Although during the data process, detector health (i.e., the observation rate of the detector) is chosen as a rule when selecting the readings. It is still possible that our estimated reading contains reading errors. Except for the influence of detector health, the detector location may also have an impact on the readings. Even though the detector deployed in this study is chosen under the categories as "Mainlane," it is still practicable to have "Mainlane" detector placed next to an on-ramp or off-ramp segment or placed at a bottleneck. These impacts reflect the point estimated readings when interpreting the magnitude of parking at a specific rest area, but these impacts are diminished to some extent by taking an aggraded truck flow reading for the inputs of the simulation.

Further, there are potentially temporal impacts from roadside during the period selected or permanent impacts along the test segment, which are out of the control of the proposed simulation as the simplifications and assumptions stated in the methodology. The temporal impacts are like a work zone, major traffic incidents, and highway maintenance. The permanent impacts are those such as private parking areas and weight stations. The simulation inexplicitly considered the fact of potential private parking areas by incorporating adjusting number to the rest area.

With all these potential external impacts listed, the results of the simulation are compared with estimated point readings for truck parking magnitude from temporal and spatial perspectives. The number of temporal truck parking is compared between estimated detector readings and simulation illustrated in Figure 4. From temporal truck parking magnitude comparison, the estimated detector readings match with simulation results mostly, such as at Aliso, Butterwillow, Coalinga/Avernal and John "Chuck" Erreca. These rest areas are located in between major cities and have constant inflow and outflow. It is notable that the simulation proposed in this study performs smoother than the estimated detector readings because the simulation considers a more extended period in space and time as input before the rest area. It shows the simulation proposed is not restricted by local effects. For example, Lebec is located about 70-miles north to Los Angeles, a city where Interstate 15, Interstate 40 and Interstate 10 are intercepted at. This large number of inflow results in the estimated detector readings being more disturbed in counting the number of trucks parking at Lebec throughout the time series of a day. Westley is a rest area with detector stations that are primarily spread out and have lower observed rates. This explains that

although the simulation results and estimated point readings are under a similar trend, the estimated point readings lose some amount of parking volume as the reading points are solely depending on the quality of closely located detectors around rest area. Hence, in terms of temporal truck flow, the predicted truck densities by simulation are similar with truck parking densities estimated from detectors. The simulation results predict more stabilized and globalized truck parking densities, whereas the point readings are influenced locally. It is significant to claim that this proposed simulation would benefit highway rest area facility control and management personnel.

Figure 5: Temporal Comparisons at Rest Areas (I-5N)

Spatially averaged daily truck magnitude comparison is also performed and presented as shown in Figure 5. From transportation planning and highway traffic management perspective, it is necessary to acknowledge the truck parking volume along the highway at an aggregated level. Reflected in Figure 5 and Figure 6, the simulation results are not only with a similar trend but also predict closed parking number results at each location. The result validates the simulation and shows the potentials of the simulation.

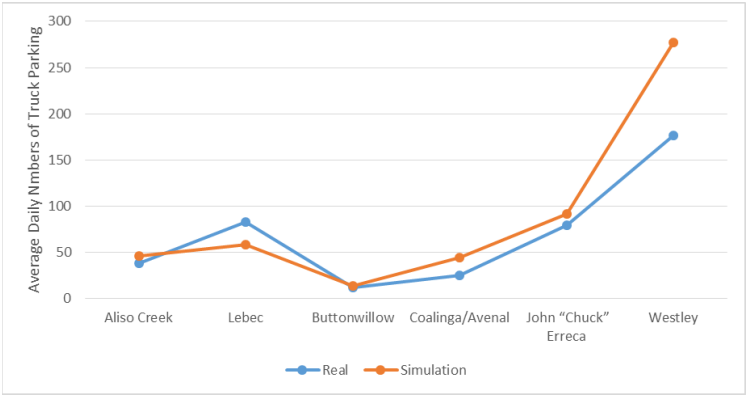

Figure 6: Spatial Comparisons at Rest Areas (I-5N)

Overall, the comparisons fairly well support the ability of the proposed simulation method and emphasize its ability to closely predict truck parking magnitude both temporally and spatially. It

demonstrates the enormous benefits of proposed simulation to both rest area facility management and highway transportation planning management.

4.4 AFFECTING FACTORS ANALYSIS

In this section, several factors, including input flow, park density, speed, rest time distribution and driving time distribution are examined to find the critical factor that might affect the simulation results.

4.4.1 Input Flow

Based on observation, there common types of arrival flow function are tested to see its influence on the number of trucks parking in the rest area. For easiness of comparison, rest area 19, which is 500 miles away from the starting point. The tested arrival flow density function is listed in Table 5. The simulation results are presented from Figure 7 to Figure 12.

Table 5: Arrival flow density function

Arrival Function	Probability Density Function (PDF)
Combination of Gaussian distributions	$y = \frac{0.5}{2\sqrt{2\pi}} e^{-\frac{(x-8)^2}{8}} + \frac{0.5}{4\sqrt{2\pi}} e^{-\frac{(x-4)^2}{32}}$
Normal distribution	$y = \frac{1}{4.5\sqrt{2\pi}} e^{-\frac{(x-13)^2}{40.5}}$
Uniform distribution	$y = \begin{cases} \frac{1}{20} & for\ x\epsilon[4,24] \\ 0 & otherwise \end{cases}$

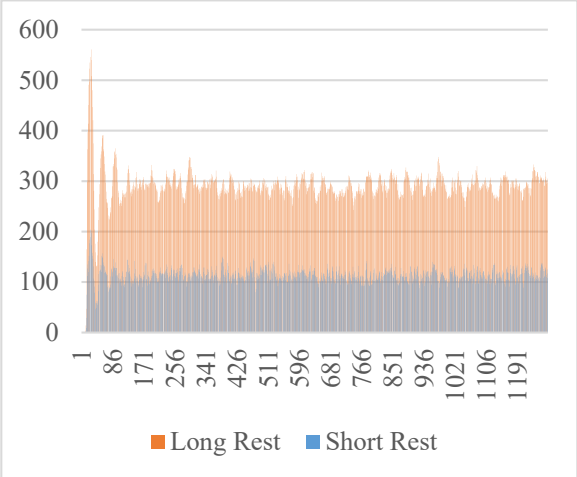

Figure 7: Number of trucks in rest at Rest Area 19 with mixture of Gaussian distributions arrival function result

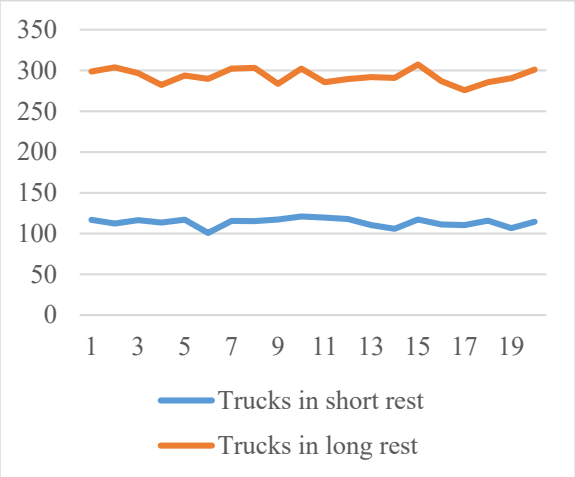

Figure 8: Number of trucks in rest at each rest area with mixture of Gaussian distributions arrival function

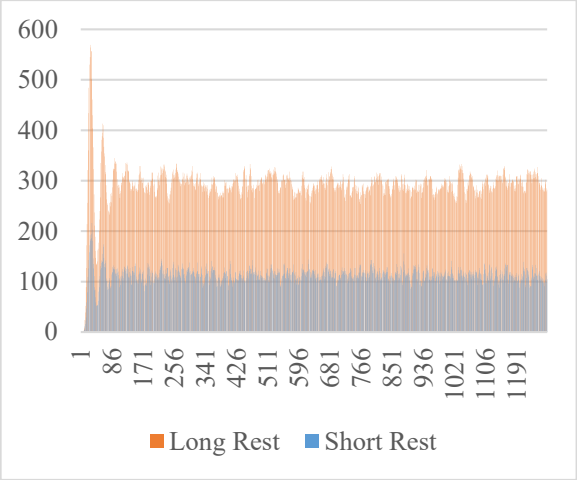

Figure 9: Number of trucks in rest at Rest Area 19 with normal distribution arrival function result

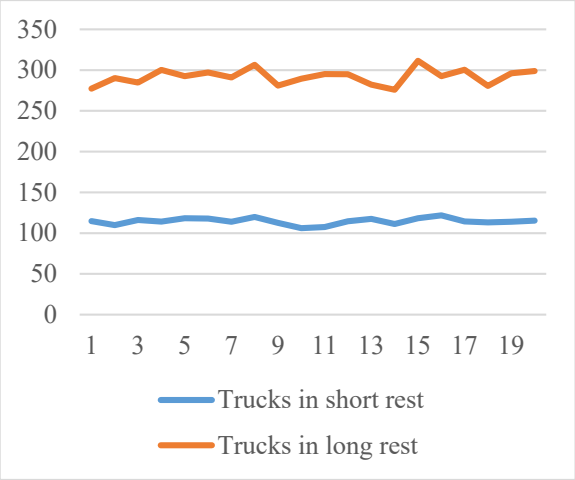

Figure 10: Number of trucks in rest at each rest area with normal distribution arrival function result

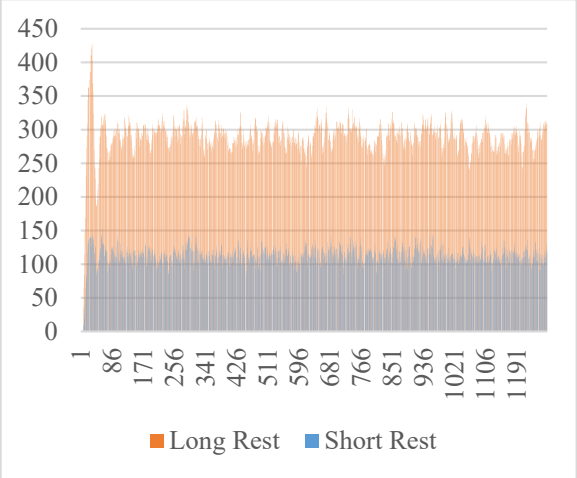

Figure 11: Number of trucks in rest at Rest Area 19 with uniform distribution arrival function result

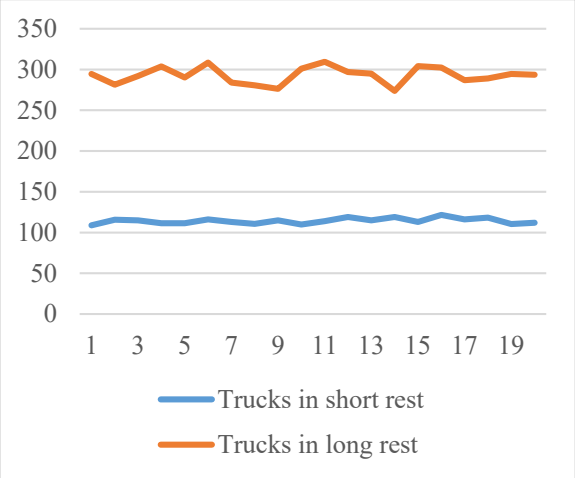

Figure 12: Number of trucks in rest at each rest area with uniform distribution arrival function result

Based on Figure 7 to Figure 12. It is easy to see that the type of arriving flow has a great impact on the initial stage of simulation. In other words, certain arrival flow may cause shock to rest areas located on the downstream highway segment, while it has little things to do with the converged value after a long time of simulation. The effect diminishes as time goes by. The major differences lie in the release stage. The arrival function with normal distribution tends to result in a surge at an early stage, which can reach as big as 561 in a single rest area. One possible explanation is that the arrival function is only useful at the input or beginning stage. The arrival flow will change after several circles in the circular simulation system. The peak value should arouse policymakers' attention. It is better to take the truck volume in peak period into consideration during the planning process.

4.4.2 Parking Density

Preliminary results of the circular simulation are shown in the following figures. The number on the x-axis stands for the number of simulation. The number on the y-axis denotes the number of trucks in the rest area. The drop of the end is probably due to the setting of simulation. The simulation is based on the number of circles driven not the total time.

The following parts are the results for different parking density, the interval of rest area ranges from 10-miles to 200-miles. In the circular simulation, the length of the circle is set to be 1000 mile. The total number of trucks in the system is 10000. The number of rest area ranges coding from 0. The x-axis stands for time spent in the simulation system, which starts with the first truck entering the system. The y-axis is the total number of trucks parking in the corresponding rest area. For illustration, the rest area located 500 miles away from the start point is examined for comparison for each situation.

Parking density of 0.1 to 0.005 mile^{-1} (corresponding to interval of 10 to 200 mile per rest area) are examined. In the first case, 0.1 parking density, there are 100 rest areas in total, coding from 0 to 99. The interval between each rest area is 10 mile. The relationship between hour in simulation and the number of the truck in rest, both in short rest and in long rest are shown in Figure 13 and Figure 14.

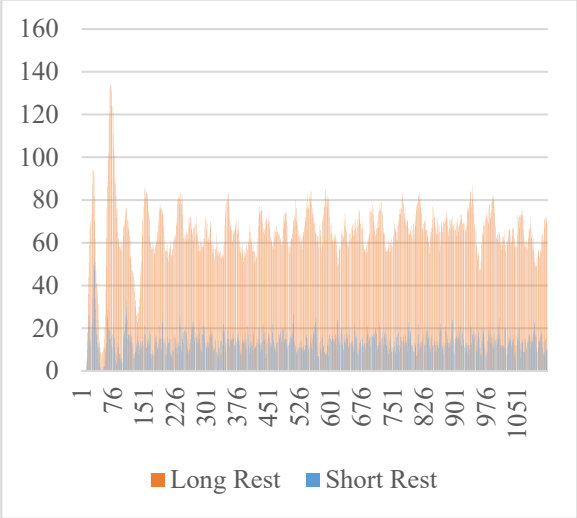

Figure 13: 0.1 parking density result at in rest at Rest Area 49

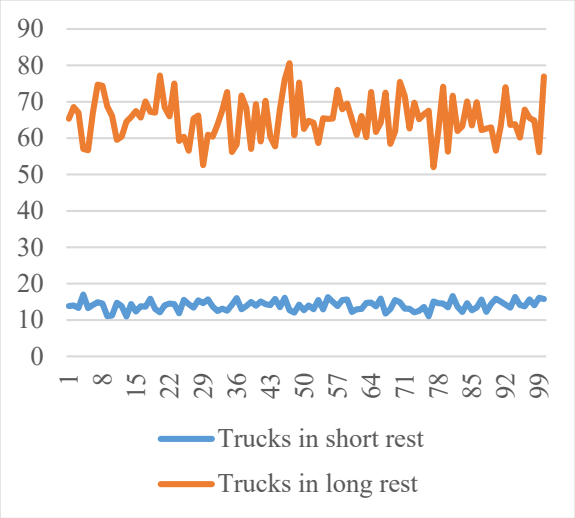

Figure 14: Number of trucks in rest at each rest area with 0.1 parking density

The average number of trucks parked in the rest area after 10000 hours of the simulation is treated as the final value. In the first case, there are approximately 20 trucks in short rest and 65 trucks in long rest in each area. The number will oscillate within a range. However, in a small parking density, the number is not stable even after a long time of simulation.

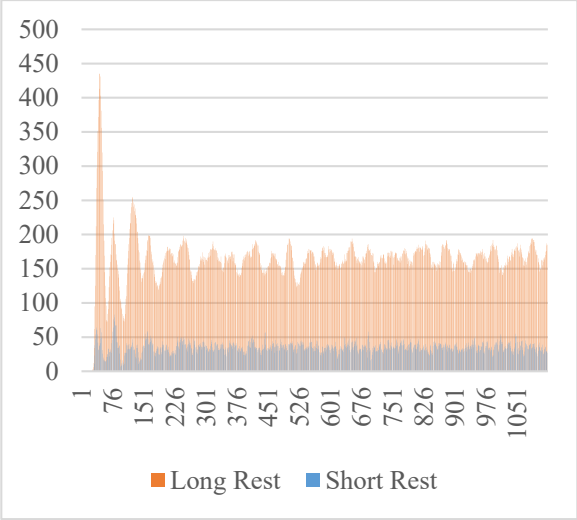

Figure 15: 0.04 parking density result at in rest at Rest Area 19

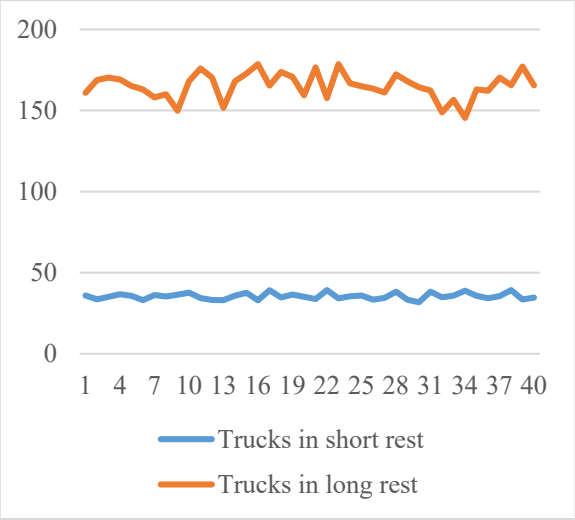

Figure 16: Number of trucks in rest at each rest area with 0.04 parking density

In the second case, 0.04 parking density, there are 40 rest areas, coding from 0 to 39. The interval between each rest area is 25 mile. The relationship between hour in simulation and the number of the truck in rest, both in short rest and in long rest are shown in Figure 15 and Figure 16.

Except for the rest area near the entering point 0, other rest areas have approximately 40 trucks in short rest in each area. Due to the large variety, it is hard to see the trend of the truck number in long rest. However, there are about 160 trucks in long rest at most rest areas.

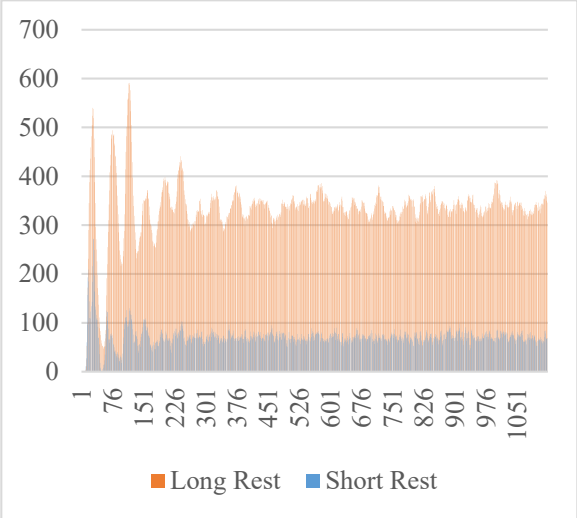

Figure 17: 0.02 parking density result at in rest at Rest Area 9

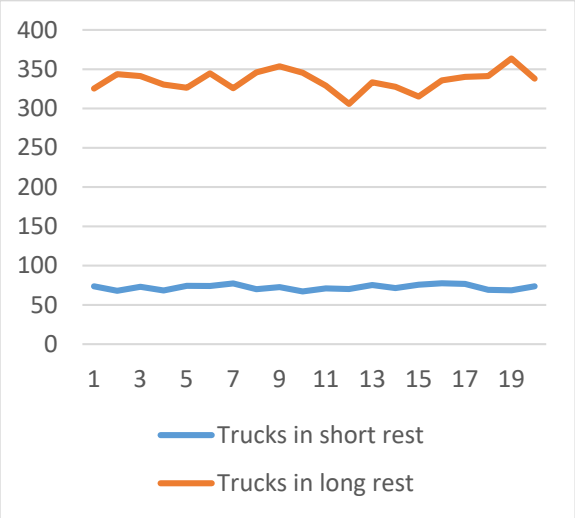

Figure 18: Number of trucks in rest at each rest area with 0.02 parking density

Except for the rest area near the entering point 0, other rest areas have approximately 70 trucks in short rest in each area. Due to the large variety, it is hard to see the trend of the truck number in long rest. However, there are about 340 trucks in long rest at most rest areas. The results are presented in Figure 17 and Figure 18.

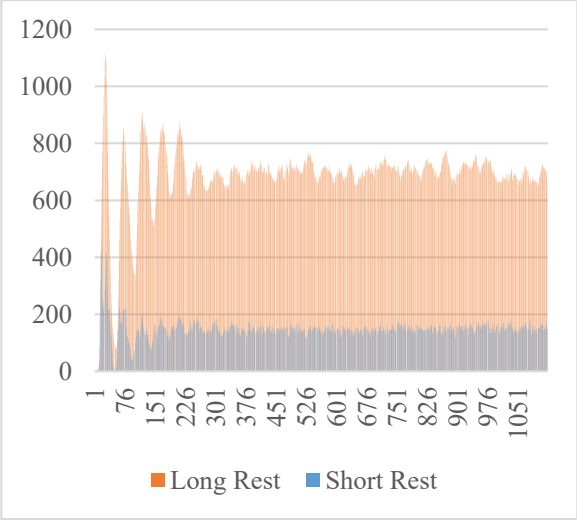

Figure 19: 0.1 parking density result at in rest at Rest Area 5

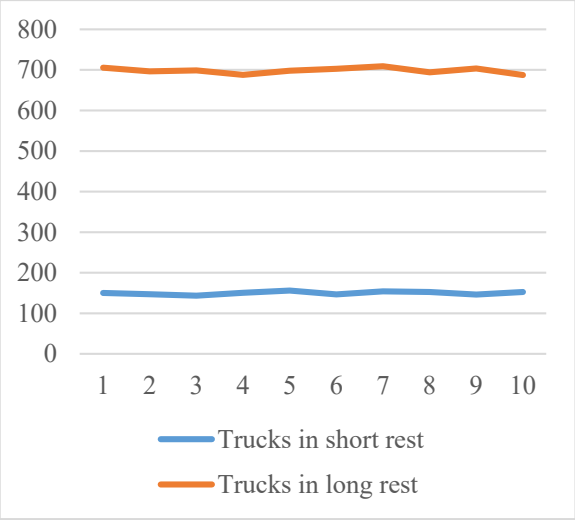

Figure 20: Number of trucks in rest at each rest area with 0.1 parking density

Except for the rest area near the entering point 0, other rest areas have approximately 150 trucks in short rest in each area. The results of 0.1 parking density are presented in Figure 19 and Figure 20. Due to the large variety, it is hard to see the trend of the truck number in long rest. However, there are about 700 trucks in long rest at most rest areas. Under 0.0067 parking density, there are approximately 220 trucks in short rest in each area. Due to the large variety, it is hard to see the trend of the truck number in long rest. However, there are about 1000 trucks in long rest at most rest areas. The results are shown from Figure 21 to Figure 22.

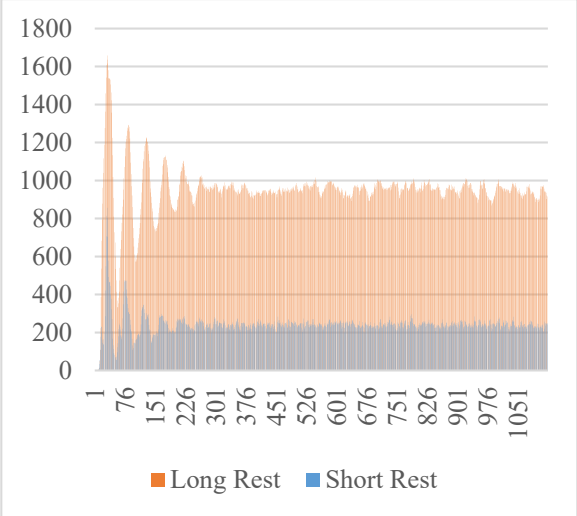

Figure 21: 0.0067 parking density result at in rest at Rest Area 3

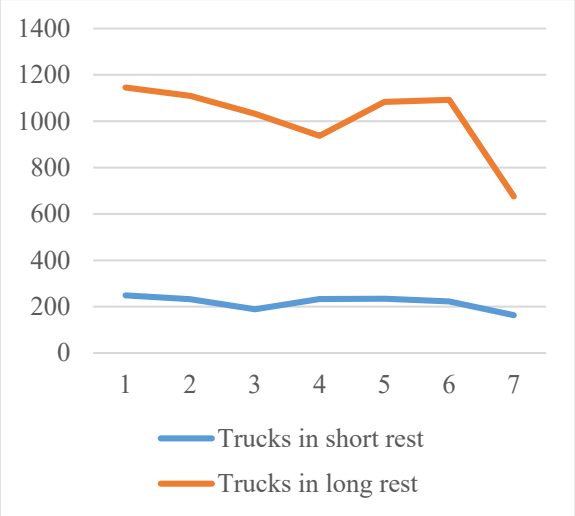

Figure 22: Number of trucks in rest at each rest area with 0.0067 parking density

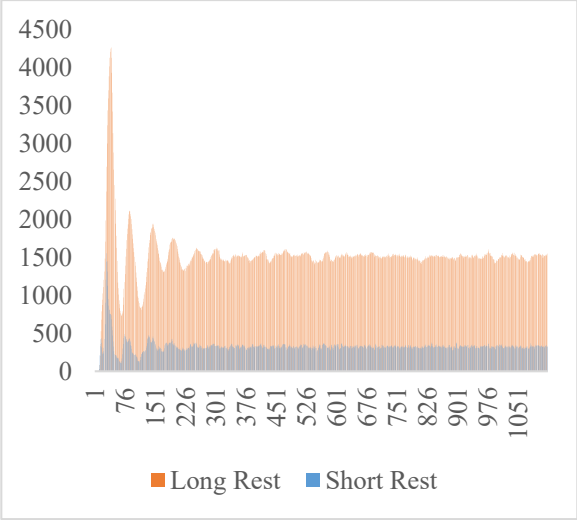

Figure 23: 0.005 parking density result at in rest at Rest Area 2

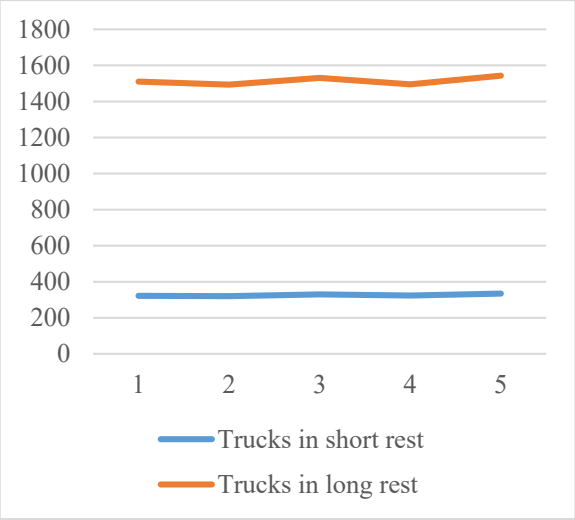

Figure 24: Number of trucks in rest at each rest area with 0.005 parking density

With 0.005 parking density, there are approximately 300 trucks in short rest in each area and there are about 1500 trucks in long rest at most rest areas. The results are shown in Figure 23 and Figure 24. The results from the above scenarios are summarized in Table 6. The number of parking trucks indicates the converged value after 10000 hours of simulation.

Table 6: Number of trucks in a rest area with different parking density

Parking interval	Parking density	Trucks in short rest	Trucks in long rest
10	0.1	14	65
25	0.04	36	165
50	0.02	72	336
100	0.01	150	698
150	0.006667	218	1011
200	0.005	326	1514

Summary of the relationship between parking density and an average number of trucks, both in short rest and long rest, at the rest area is shown in the Figure 25 and Figure 26. We can observe a negative exponential relationship between the parking density and number of trucks in the rest area. The number of trucks in the rest area will converge to the expected average number very quickly. In 24 hours, the number of the trucks in the rest area shifts around the average amount. With the increasing of parking density, the number of trucks parked in each area shows a more extensive variety and converge faster. For example, it takes around 170 hours in 0.1 (10-miles) parking density to converge while the time increases to 247 hours to reach a balance in the 200-miles case. In addition, at the end of the simulation, the number of trucks in rest area oscillation is around 10% in 0.02(50-miles) case, but the amount decreases to 4 % when parking density reaches 0.005 (200-miles). When there are plenty of parking facilities, truckers can choose rest area relatively freely. However, with less number of rest areas, there is no wonder that the truck will concentrate on a single rest area, which will potentially result in a parking shortage.

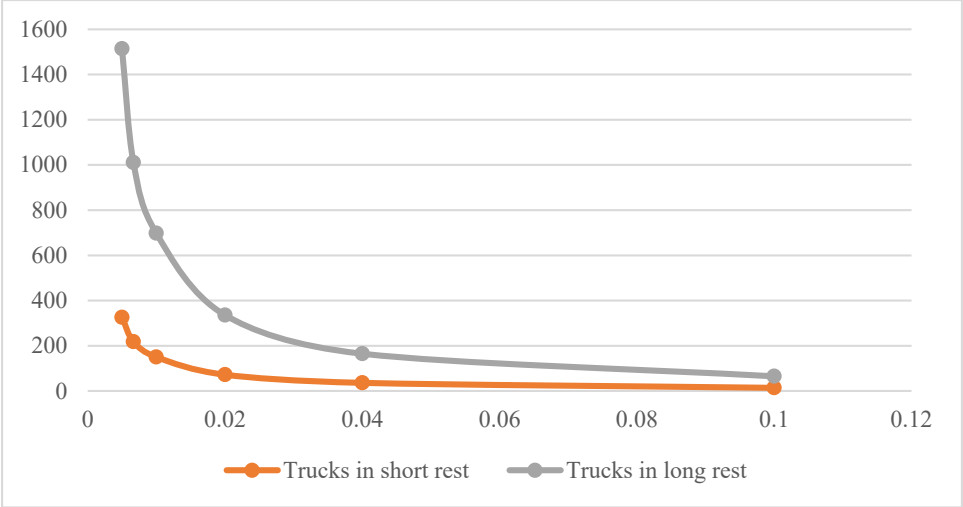

Figure 25: Number of trucks in rest at each rest area under different parking density

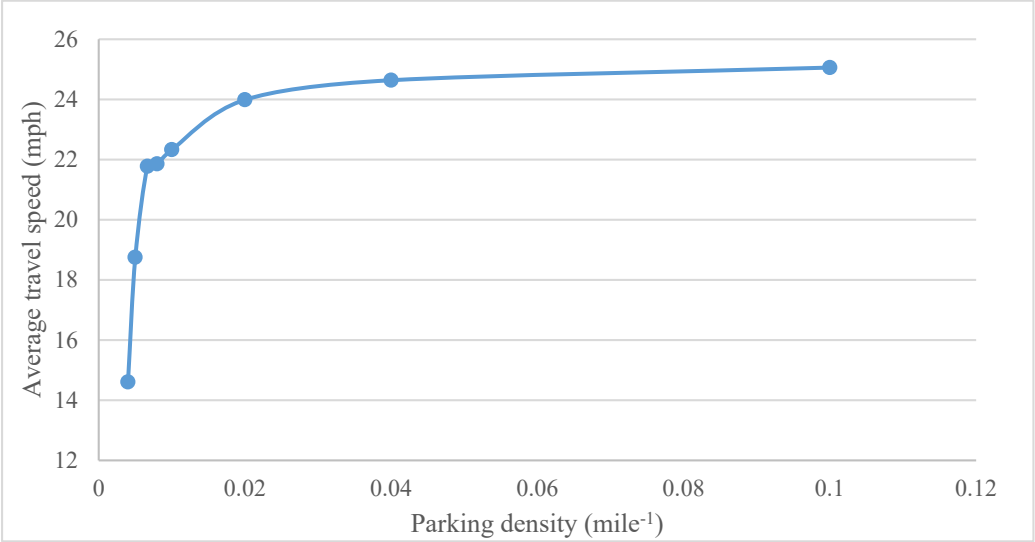

Figure 26 Average travel speed of the trucks under different parking density

Though the daily number of rest trucker largely correlates with the input traffic flow at the beginning of the simulation, the coverage number has little to do with the input traffic flow at the final stage. Another interesting fact is that the total number of trucks in long rest is approximately 4.6 times of that in short rest.

Summary of the relationship between the average travel speed of the trucks and parking density is shown in Figure 6. The number on the x-axis stands for the parking density. The average travel speed of trucks is denoted by the number on the y-axis, measuring in mph. The interval of rest area ranges from 10-miles to 200-miles. The parking space density is defined as reciprocal of the interval, which ranges from to 0.005 to 0.1 rest area per mile. Measuring the average travel speed of trucks makes it possible to quantify the impact of publicly provided infrastructure on the private operations. The result shows that the average travel speed of trucks increases with the increase in rest area density. The speed rises faster at lower parking density and the slow down approaching a specific value. Under the assumption of 65 mph cruise speed, the breakpoint is

around 0.2, which correspond to the 50-mile interval. The average travel speed reduces significantly when the rest area density is below 0.015. The lower the density is, the less likely truck drivers to find a proper rest area in general. Truck drivers have to sacrifice their driving time to obey the hours-of-service regulation. Denser rest area may be helpful, but not significant. In other words, 50 to 70 miles is likely to be a proper spacing for building rest area on the highway segment without substantial disturbance. Based on the result, the conclusion matches the American Association of State Highway and Transportation Officials (AASHTO) standard, which recommends safety rest area spacing at approximately 60 miles or an hour apart on the National highway system. (American Association of State Highways and Transportation Officials, 2001)

4.4.3 Speed

Trucks with speed ranging from 45 mph to 80 mph are also examined. It aims to see whether there is an impact on parking density with the change of the cruise speed. The test was conducted on 1000 mile long circular system mentioned above with parking density of 0.02 (one rest area per 50-miles). The arrival flow is also assumed to be a double-head distribution, which is the same as the definition above. The x-axis denotes the time spent in the simulation system, which starts with the first truck entering the system. The y-axis is the total number of trucks parking in the corresponding rest area. For comparison, the rest area located at 500-miles away from the start point is examined for comparison for each situation. The results are shown from Figure 27 to Figure 41.

Figure 27: Number of trucks in rest at Rest Area 19 with 45 mph cruise speed

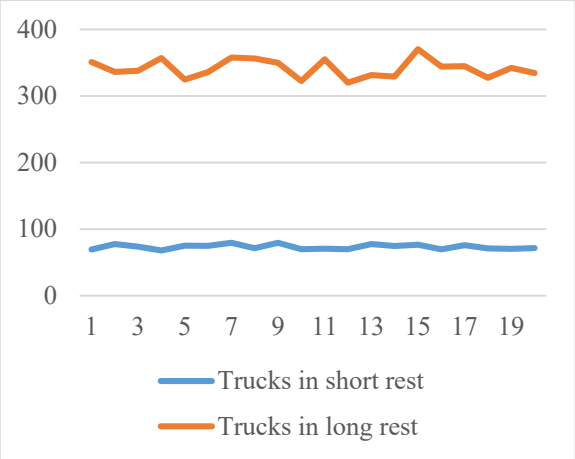

Figure 28: Number of trucks in rest at each rest area with 45 mph cruise speed

Figure 29: Number of trucks in rest at Rest Area 19 with 50 mph cruise speed result

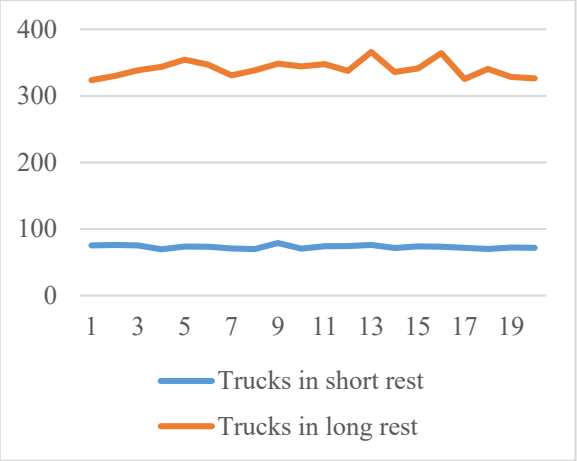

Figure 30: Number of trucks in rest at each rest area with 50 mph cruise speed result

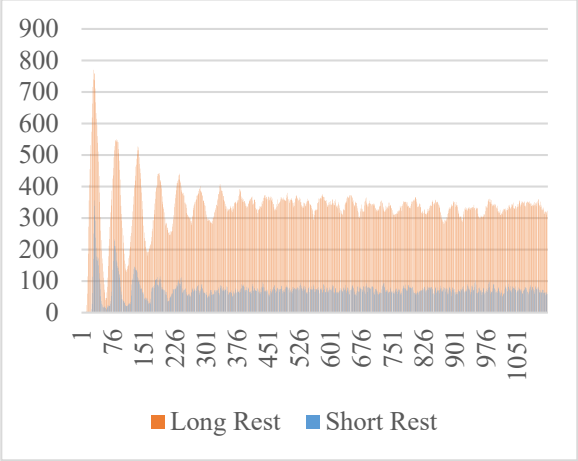

Figure 31: Number of trucks in rest at Rest Area 19 with 55 mph cruise speed result

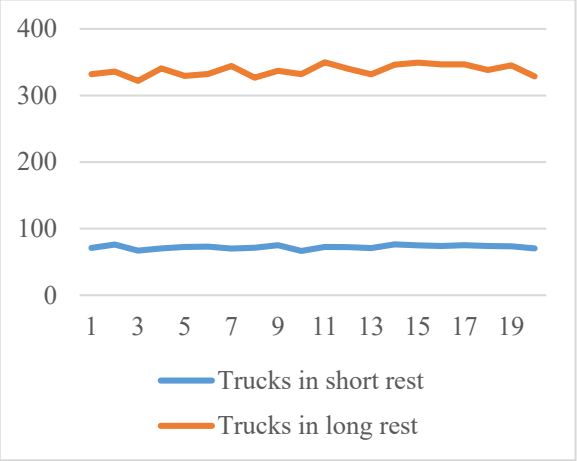

Figure 32: Number of trucks in rest at each rest area with 55 mph cruise speed result

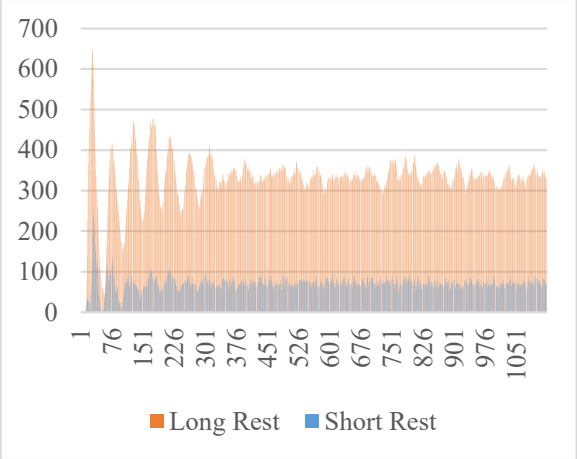

Figure 33: Number of trucks in rest at Rest Area 19 with 60 mph cruise speed result

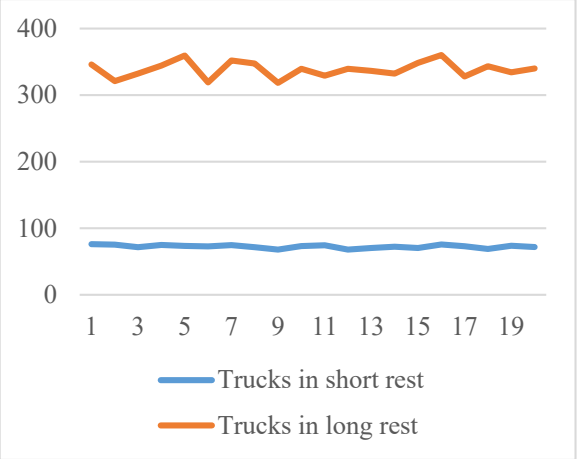

Figure 34: Number of trucks in rest at each rest area with 60 mph cruise speed result

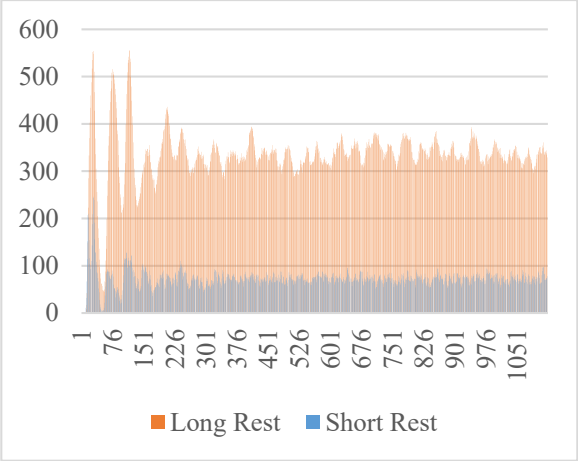

Figure 35: Number of trucks in rest at Rest Area 19 with 65 mph cruise speed result

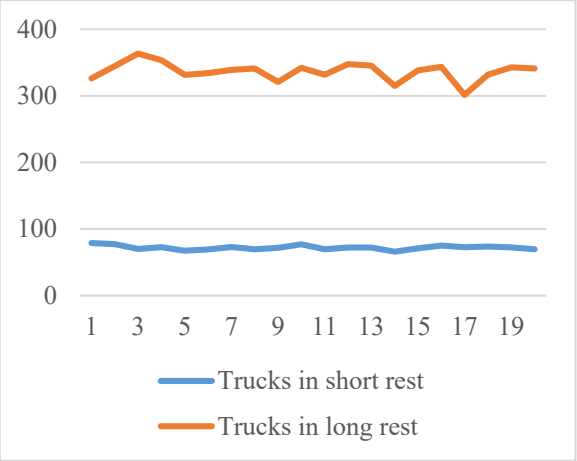

Figure 36: Number of trucks in rest at each rest area with 65 mph cruise speed result

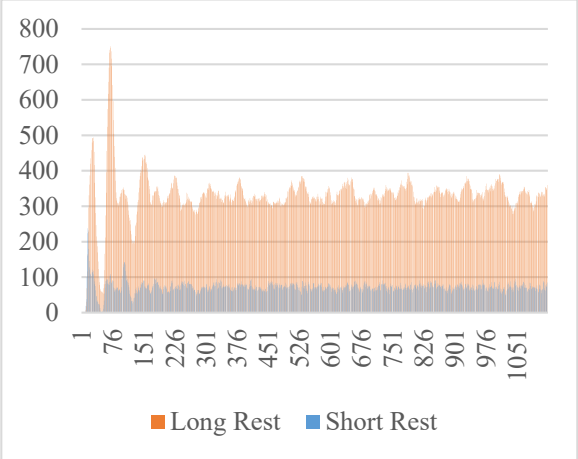

Figure 37: Number of trucks in rest at Rest Area 19 with 70 mph cruise speed result

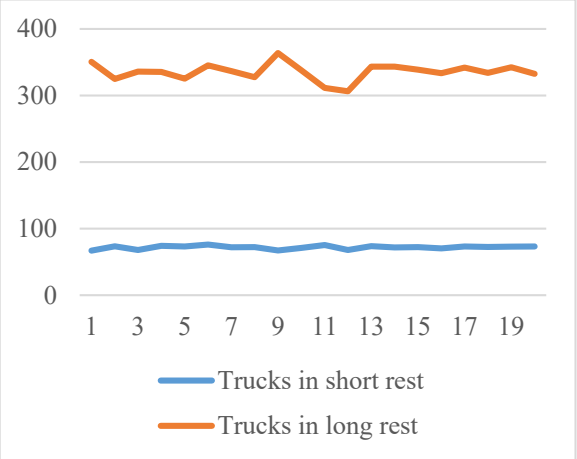

Figure 38: Number of trucks in rest at each rest area with 70 mph cruise speed result

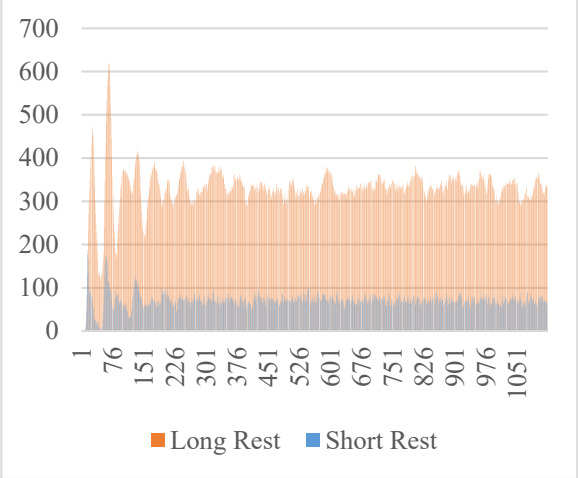

Figure 39: Number of trucks in rest at Rest Area 19 with 75 mph cruise speed result

Figure 40: Number of trucks in rest at each rest area with 75 mph cruise speed result

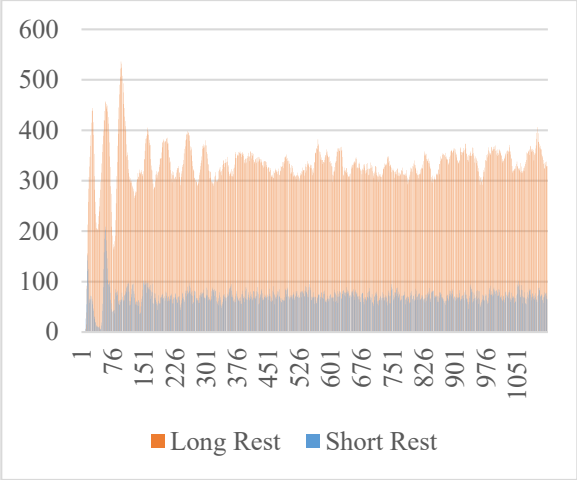

Figure 41: Number of trucks in rest at Rest Area 19 with 80 mph cruise speed result

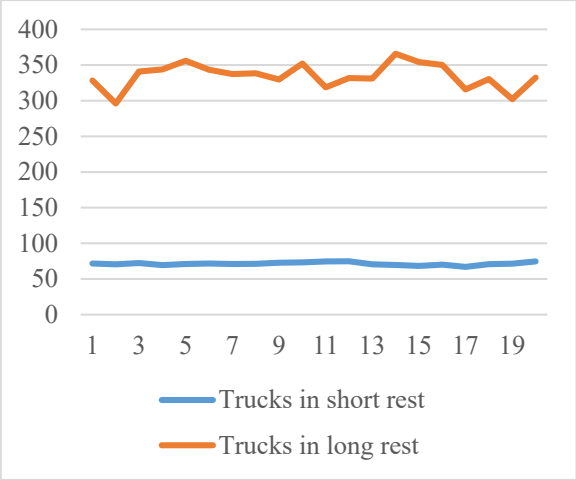

Figure 42: Number of trucks in rest at each rest area with 80 mph cruise speed result

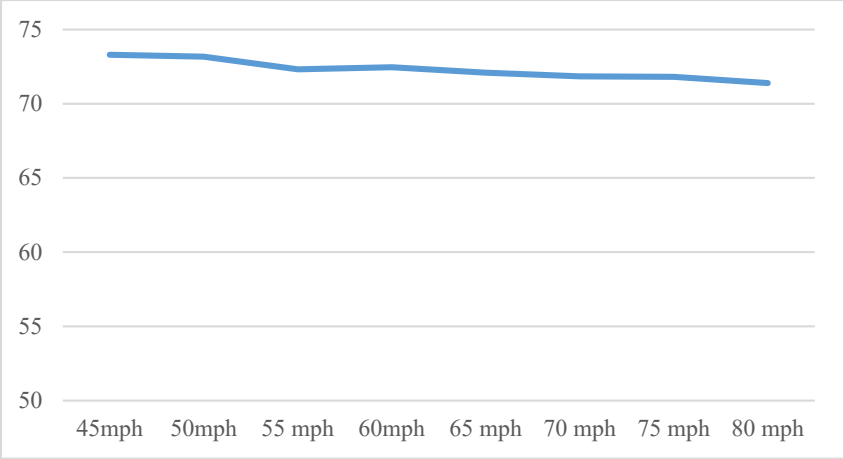

Figure 43: Average number of trucks in short rest with different speed

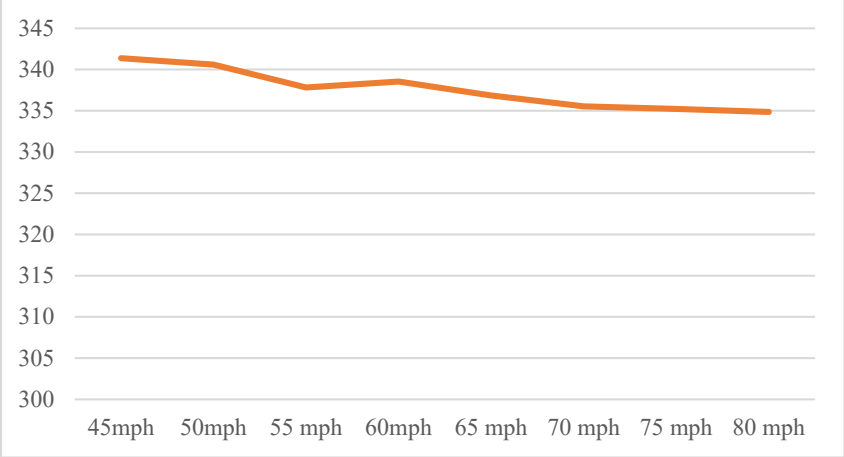

Figure 44: Average number of trucks in long rest with different speed

It is easy to see the number of rest truck in each area will converge to a certain value and oscillated with the value after a long time though the value is different between each rest area. Overall, converge speed is very fast, usually within 100 hours (in simulation time) after the start. However, in the real world, the phenomenon is less likely to be observed because the process takes at least 5 five days. Comparing the number of trucks in short rest at the same rest area with different cruise speed, it is easy to see that the convergence happens faster with the increase of cruise speed of trucks and the process is smoother than that under low cruise speed. Speed has little effect upon the average number of trucks in rest.

4.4.4 Rest Time Distribution

Based on observation, there common types of arrival flow function are tested to see its influence on the number of trucks parking in the rest area. For easiness of comparison, rest area 19 is chosen, which is 500-miles away from the starting point. The tested arrival flow density function is listed in Table 7.

Table 7: Arrival flow density function

Case No.	Short rest time distribution	Long rest time distribution
1	Lognormal distribution (0.1, 0.1) $y = \frac{1}{0.1x\sqrt{2\pi}} e^{-\frac{(x-0.1)^2}{0.02}}$	Uniform distribution $y = \begin{cases} \frac{1}{5} & for\ x\epsilon[10,15] \\ 0 & otherwise \end{cases}$
2	Lognormal distribution (0.1, 0.1) $y = \frac{1}{0.1x\sqrt{2\pi}} e^{-\frac{(\ln x-0.1)^2}{0.02}}$	Normal distribution (11, 0.5) $y = \frac{1}{0.5\sqrt{2\pi}} e^{-\frac{(x-11)^2}{0.5}}$
3	Lognormal distribution (0.1, 0.1) $y = \frac{1}{0.1x\sqrt{2\pi}} e^{-\frac{(\ln x-0.1)^2}{0.02}}$	Shifted lognormal distribution (0.1, 1) $y = \frac{1}{(x-10)\sqrt{2\pi}} e^{-\frac{(\ln(x-10)-0.1)^2}{2}}$
4	Lognormal distribution (0.1, 0.1) $y = \frac{1}{0.1x\sqrt{2\pi}} e^{-\frac{(x-0.1)^2}{0.02}}$	Uniform distribution $y = \begin{cases} 2 & for\ x\epsilon[15,20] \\ 0 & otherwise \end{cases}$

It is assumed that all the drivers will obey the hours-of-service (HOS) regulation and will not drive more time than required. As it is mentioned in the previous part, the minimum rest time for short is 0.5 hour and the minimum hour for long rest is 10 hour. Short rest time ranges from 0.5 hours to 1.5 hours. Several scenarios of long rest, including different duration and different type of distribution, are discussed because truckers in the long rest are more likely to increase occupancy and thus result in a shortage of parking. Extremely long stay in the rest area will be either truncated or allocated at a tiny probability according to different situations. The results are presented from Figure 45 to Figure 52.

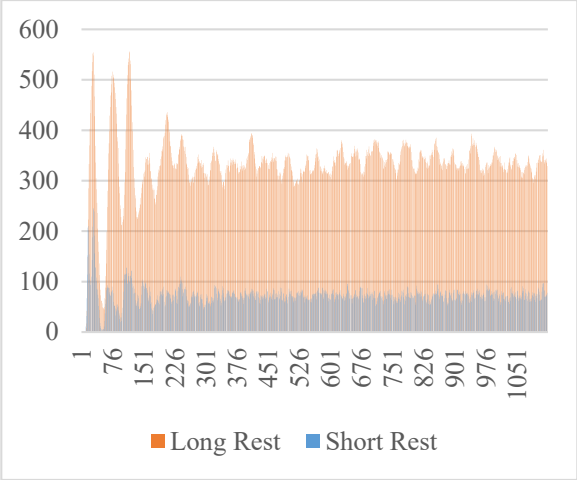

Figure 45: Number of trucks in rest at Rest Area 19 in case 1

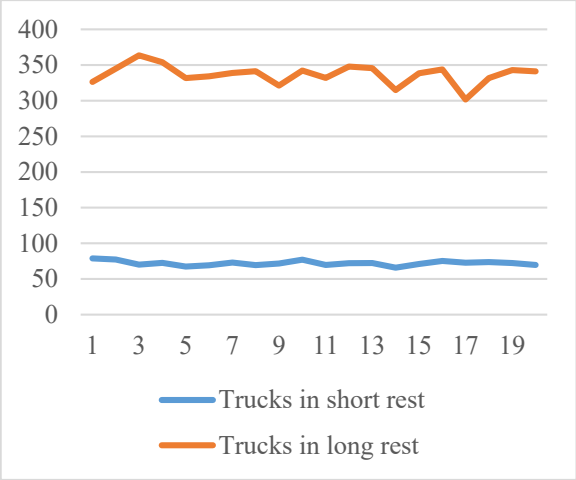

Figure 46: Number of trucks in rest at each rest area in case 1

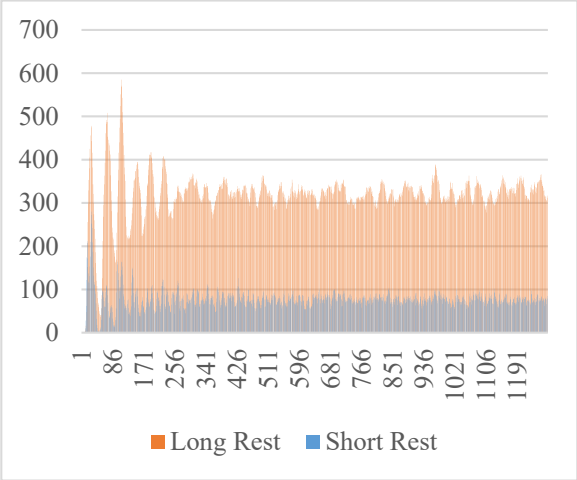

Figure 47: Number of trucks in rest at Rest Area 19 in case 2

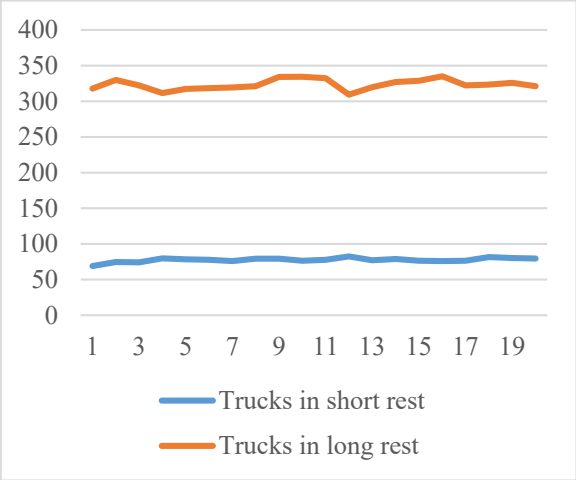

Figure 48: Number of trucks in rest at each rest area in case 2

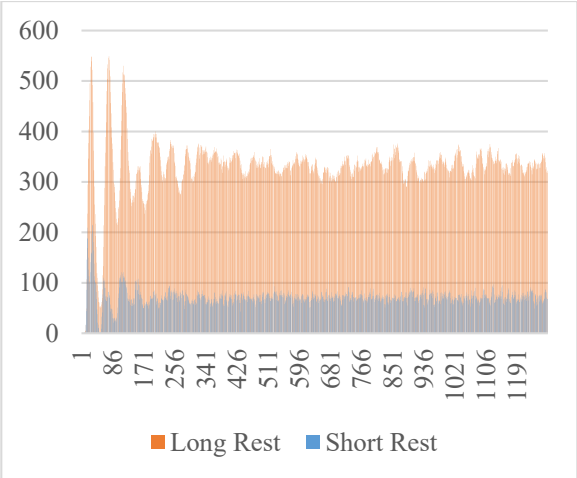

Figure 49: Number of trucks in rest at Rest Area 19 in case 3

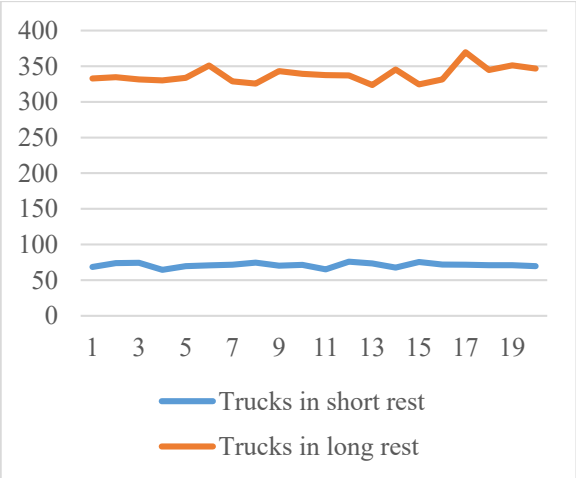

Figure 50: Number of trucks in rest at each rest area in case 3

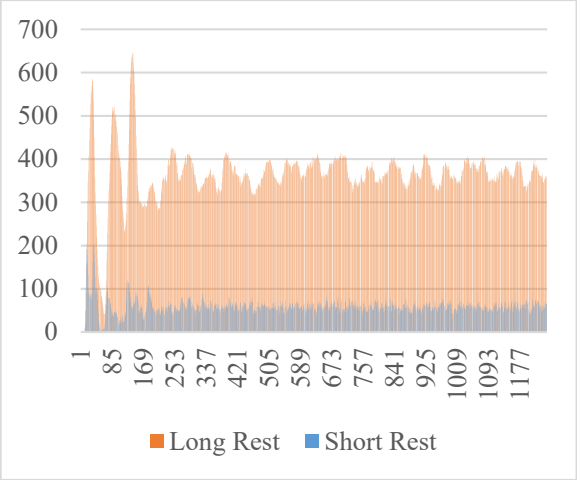

Figure 51: Number of trucks in rest at Rest Area 19 in case 4

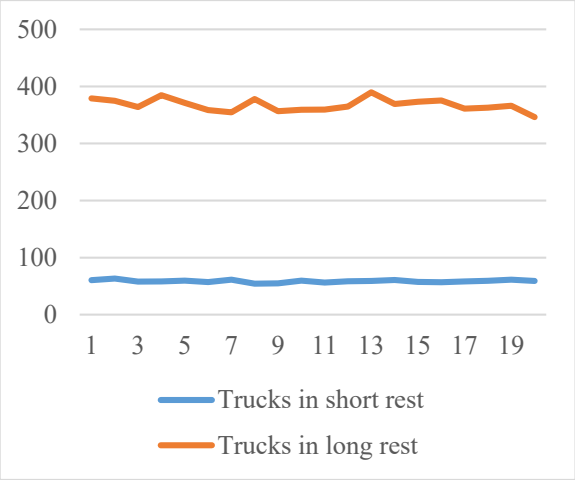

Figure 52: Number of trucks in rest at each rest area in case 4

Table 8: Driving time distribution

Case No.	First driving time distribution	Second driving time distribution
5	Normal distribution (7.5, 0.5) $y = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-7.5)^2}{0.5}}$	Normal distribution (2.5, 0.5) $y = \frac{1}{15\sqrt{2\pi}} e^{-\frac{(x-2.5)^2}{0.5}}$
6	Normal distribution (5, 0.5) $y = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-5)^2}{0.5}}$	Normal distribution (5, 0.5) $y = \frac{1}{15\sqrt{2\pi}} e^{-\frac{(x-5)^2}{0.5}}$
7	Normal distribution (7.5, 0.5) $y = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-7.5)^2}{0.5}}$	Normal distribution (2.5, 15) $y = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-2.5)^2}{450}}$

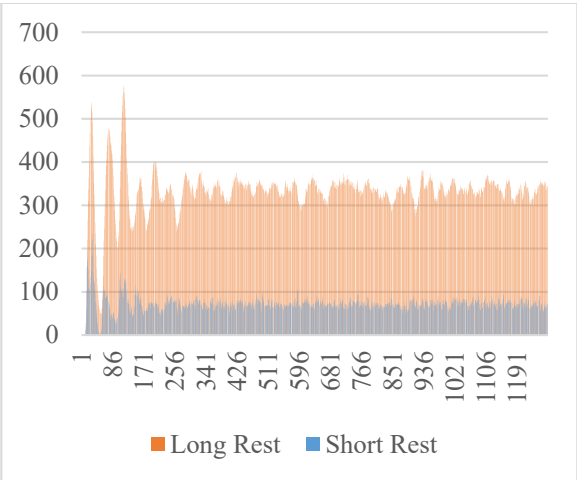

Figure 53: Number of trucks in rest at Rest Area 19 in case 5

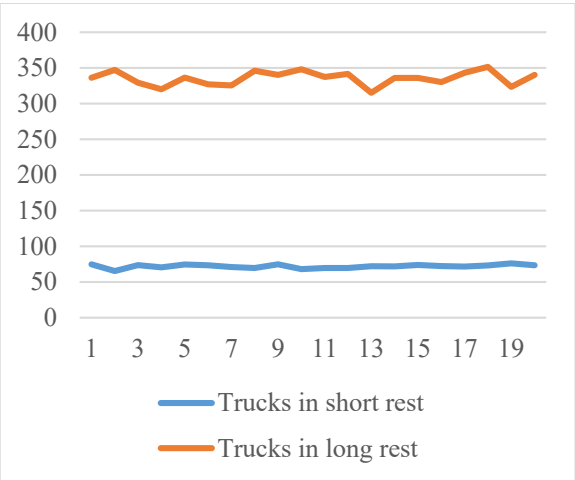

Figure 54: Number of trucks in rest at each rest area in case 5

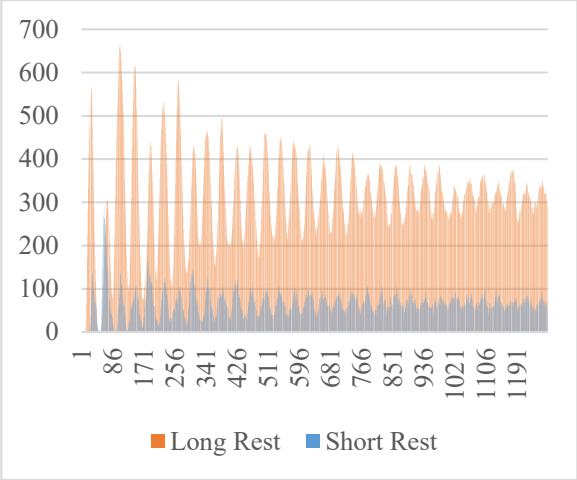

Figure 55: Number of trucks in rest at Rest Area 19 in case 6

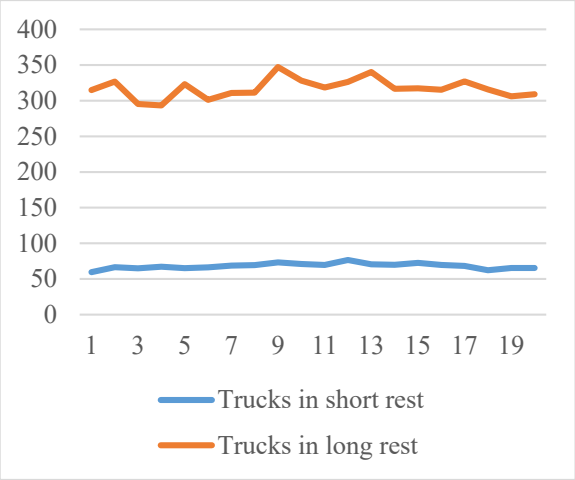

Figure 56: Number of trucks in rest at each rest area in case 6

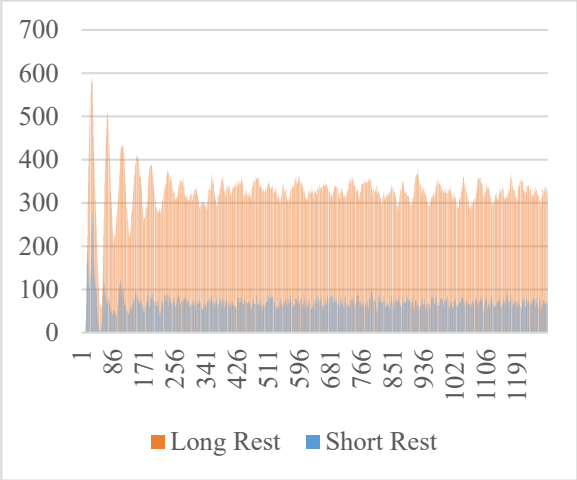

Figure 57: Number of trucks in rest at Rest Area 19 in case 7

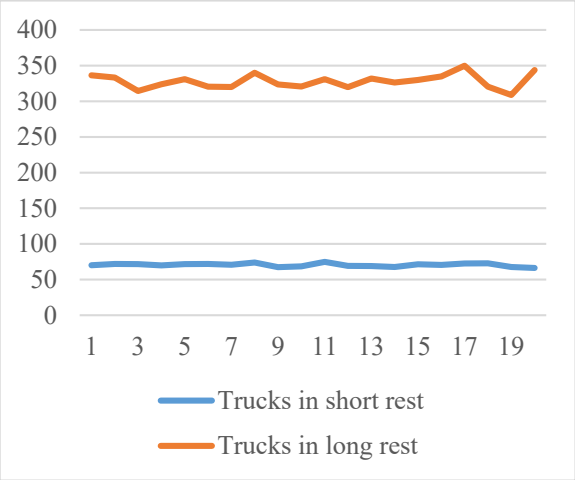

Figure 58: Number of trucks in rest at each rest area in case 7

The pattern before convergence is entirely different, but the convergence holds when changing rest time distribution. The longer truck drivers spent in the rest area, the slower the convergence is. The averaging of driving time will bring less shock to the downstream rest area but will require more space as well. The tested cases are shown in Table 8 and corresponding results are presented from Figure 53 to Figure 58. Average distribution of driving time before taking rest may result in a great impact to the nearest rest area in the downstream and following rest area for a significantly long time. In other words, the truckers' maximization of their driving time in the first part brings less shock to the downstream parking facilities. For the other case, in the beginning, more variety will result in more shock to the near rest area, but the effect will diminish as time pass by and finally reach a stable stage.

The decision of short rest point has a significant influence on the total number needed for both short and long rest. The averaging distribution of two driving parts will add more variety to the number of parking. However, under both circumstance, the parking truck at each rest area will oscillate around the same value after a long time.

5.0 CONCLUSION

The objective of the research is to figure out the relationship between the incoming truck volume and the parking capacity needed for the rest area under the hours-of-service (HOS) regulations through computer simulation. The report reviewed previous states and industry's studies and summarized their modeling methods and potential solutions to the shortage issue. The report also describes a simulation approach to find the reason behind the problem.

The simulation system can be used to estimate not only a single parking facility, but also parking demand along with a highway segment. The system incorporates various factors which have been known to affect the need for truck parking, including traffic engineering factors (truck flow), truck drivers' behaviors (duration of driving and time spent in the rest area) and most importantly, Hours-of-services regulations (daily driving limits). Detail steps for constructing the model and simulation procedures are presented. Factors that may affect the simulation results are analyzed in detail. A case of trucking parking on I-5 in California is used to test the effectiveness of the proposed simulation method. The results show that the proposed method is able to predict the truck parking magnitude quite accurately. Different parking densities are tested, and the corresponding average travel speeds are obtained. The results indicate that the average travel speed increases as the parking density decrease, and will finally converge to an expected number. Other factors that might affect the simulation results are examined as well. The results show that arriving flow, especially which during peak hour, impose an enormous impact on the initial stage of the simulation, while speed only has little effect.

The most critical finding in this report is that the number of trucks in a rest area, after a long time of simulation time, will converge to a specific value. The result can be interpreted that the number of truck parking in the rest area remains stable for a highway section without significant input or output truck flow from upstream. The number of trucks in the rest area continues in a particular pattern in a day if there is a little shock, for example, a significant number of truck arriving within a short period, from upstream. The variety in the number of trucks in the long rest parking is higher than that in short rest, which can probably attribute to a large variety of long rest time spent in the rest area of the individual truck driver. Arrival flows may cause shock to downstream parking facilities. The shock will diminish after a significantly long time. As for parking density, it can observe a negative exponential relationship between the parking density and number of trucks in the rest area for converged values. Large parking density can ease the shock generated by arrival flow. The shock will last longer in a situation with a large interval of parking facilities. Convergence happens faster with the increase of cruise speed of trucks, and the process is smoother than that under low cruise speed through speed does not affect the much average number of trucks in rest. In general, longer rest will result in a more substantial number of truck staying in a rest area, which meets the ordinary senses. Surprisingly, the choice of breakpoint has an unneglectable influence on the number of trucks parking rest area. Under the assumption of taking only one short rest within a day, averaging of their driving time before taking interval rest will result in an enormous impact to the nearest rest area in the downstream and following rest area for a significantly long time. The phenomenon provides new ideas to ease parking shortage from scheduling sides. Logistic companies are encouraged to maximize the first part of the driving time of their drivers.

The proposed simulation system would help measure the productivity of the truckers on the highway by the average travel speed over the driving and rest time. It will also assist policy makers or planners to quantify the impact of publicly provided infrastructure on the private operations.

The proposed simulation system would help people to consider trucking parking problem from different prospect rather than conducting the survey, which is more cost efficient. The simulation outcomes are beneficial for future rest area facility management and highway management. Future work includes setting up highway network framework other than a linear system, testing more real cases and proposing mathematical models of various factors.

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