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Application of Connected Truck Data to Evaluate Spatiotemporal Impact of Rest Area Closures on Ramp Parking

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Abstract

Ensuring adequate access to truck parking is critical to the safe and efficient movement of freight traffic. There are strict federal guidelines for commercial truck driver rest periods. Rest areas and private truck stops are the only places for the trucks to stop legally and safely. In locations without sufficient parking areas, trucks often park on interstate ramps, which create safety risks for other interstate motorists. Historically, agencies have employed costly and time intensive manual counting methods, camera surveillance, and driver surveys to assess truck parking. Connected truck data, available in near real-time, offers an efficient alternative to practitioners to assess truck parking patterns and identify areas where there may be insufficient safe parking spaces. This paper presents a case study of interstate I-70 in east central Indiana and documents the observed spatiotemporal impacts of a rest area closure on truck parking on nearby interstate ramps. Results showed that there was a 28% increase in parking on ramps during the rest area closure. Analysis also found that ramps closest to the rest area were most impacted by the closure, seeing a rise in truck parking sessions as high as 2.7 times. Parking duration on the ramps during rest area closure also increased drastically. Although it was expected that this would result in increased parking by trucks on adjacent ramps, this before, during, after scenario provided an ideal scenario to evaluate the robustness of these techniques to assess changing parking characteristics of long-haul commercial trucks. The data analytics and visualization tools presented in this study are scalable nationwide and will aid stakeholders in informed data-driven decision making when allocating resources towards improving the nation's commercial vehicle parking infrastructure.

Keywords

Connected Truck Data, Rest Areas, Exit Ramps, Truck Parking, Commercial

Vehicles

1. Introduction

The Bureau of Transportation Statistics estimates that trucks moved about 65% of freight by tonnage in the United States in 2017, 64.7% in 2023, and expects this number to rise to about 67% by 2050 [1]. Lack of sufficient truck parking availability often leads to trucks parking in unsafe locations such as exit ramps, entry ramps or shoulders, thus increasing the potential for collisions and possibly damaging transportation infrastructure not built to withstand heavy-vehicle parking [2] (**Figure 1**). It is important that commercial vehicle drivers have access to reliable truck parking facilities for the safety of all highway users and to ensure compliance with hours-of-service regulations established by the Federal Motor Carrier Safety Administration (FMCSA) [3]. A growing shortage of truck parking at the national level poses severe safety concerns for commercial vehicle drivers as well as the general motoring public.

Recognition of this problem at the federal and state level has resulted in many grants being apportioned in recent years for building newer truck parking facilities

Figure 1. Two panoramic views showing a total of 15 trucks parked on the rural I-70 Rest Area ramps in Plainfield, IN around 04:23 AM on April 03, 2024 (truck 7, 8 10, 11 in both images).

as well as capacity additions at existing locations. A 2015 survey (commonly known as the Jason's Law Truck Parking Survey) highlighted the nationwide truck parking capacity and information shortage [4]. Most states reported truck parking shortages as well as almost half of the state DOTs reported illegal parking problems on interstate ramps and shoulders driven by a lack of capacity. The survey reported that on average there are 7.63 private truck parking spaces for each public rest area space in the US. As a consequence of these identified truck parking shortages, the FMCSA announced in September 2023 approximately $80 million in grants to improve truck parking information dissemination on parking availability [5]. A recent $292 million grant awarded an additional fund to improve truck parking capacity in Florida, Missouri, Wisconsin and on the west coast [6]. Indiana also committed to investing over $600 million over the next decade to add more than 1000 truck parking spaces to alleviate this problem [7].

The Truck Parking Development Handbook [8], driver's license manuals and administrative codes [9] for states observe that ramp parking is prohibited in most US states due to the safety concerns it poses for all highway users and even carries with its citations in some states. Anecdotal evidence from state departments of transportation (DOT), law enforcement and the trucking industry suggest a lack of available truck parking spaces results in instances of illegal parking along freeway ramps, shoulders or local streets.

Emerging sources of connected truck data provide all relevant stakeholders with a unique opportunity to quantifiably depict the national truck parking shortage to present decision makers with the relevant data towards alleviating this problem. The following section covers a brief review of current practices adopted by stakeholders for measuring truck parking capacity performance and identifying potential gaps and highlights emerging practices using connected vehicle and connected truck data that may enable more efficient performance measurement.

2. Literature Review

Surveys have been the most widely preferred method among researchers and practitioners in the past to understand and analyze truck parking trends in highway rest areas and interchange ramps. An overnight survey of truck parking in Tennessee in the year 2000 found that nearly 40 percent of trucks were parked alongside shoulders of ramps and through lanes [10]. Similar surveys and on-site data collections have been conducted over the past two decades in states such as Florida [11], Virginia [12], California [13] and found that demand for truck parking exceeds available spaces. A 2018 travel diary study on 148 U.S. drivers found that nearly 90% of drivers parked in an unauthorized location such as a ramp or shoulder at least once a week [14].

Studies have also used commercial vehicle GPS data from fleets in selected geographic regions to observe truck parking trends at rest areas and on and off-ramps connected to rest areas [15] [16] [17]. However, as has been widely recognized across the US, due to a shortage in existing facilities, trucks often park on freeway exit and entry ramps due to the convenience and quick return to freeway option that this arrangement allows for leading to increased crash risk [18]. A 10-year analysis of more than 2 million collisions in California observed that trucks were the primary vehicle-type involved in rest area ramp crashes [19], while Kentucky observed 239 crashes between 2010 and 2013 involving either driver fatigue and/or unauthorized shoulder or ramp usage by a commercial vehicle [20]. There have been multiple instances of rest areas closing for construction and having an adverse impact by means of trucks parking on the rest area entry and exit ramps and posing safety issues. While past research has focused on truck rest areas almost exclusively, there is a need to systematically analyze truck dwell patterns within rest stops as well as the surrounding network of interstate ramps for an overall assessment of truck parking patterns, to identify in gaps in parking availability. Transportation agencies currently utilize a number of time, cost and fixed infrastructure intensive techniques including visual inspections and manual overnight counts, driver surveys, travel diaries and fixed cameras to observe truck dwell and parking patterns [21] [22] [23] [24]. These techniques however do not scale at the national or even statewide level where FHWA estimates the total number of truck parking spaces in the US at 313,000 with 40,000 of them being located in public rest areas or service plazas [25].

Connected truck trajectory data has been used in recent years for multiple highway safety and monitoring applications including the observation of commercial vehicle speed trends in states with and without differential speed limits such as Illinois, Indiana, Ohio, West Virginia and Pennsylvania [26]. Past studies have shown connected truck data provides important context for roadway conditions during low volume hours and overall adds about 1% - 2% to the total share of connected vehicle penetration [27]. This data has proven to be an effective complement to connected vehicle data from passenger cars and has helped present a more complete outlook of roadway mobility and is already being used in daily operational decision making year-round in the state of Indiana. While a majority of manual truck parking count collection efforts focus on overnight truck parking between the hours of 10 PM and 6 AM, connected truck data easily scales to provide a 24-hour characterization of truck parking behavior over several months without additional labor or infrastructure investments. Data-driven insights obtained from connected vehicle methodologies will help inform infrastructure investment decision-making for truck parking stakeholders as well as commercial vehicle drivers.

3. Study Objectives and Scope

This study uses emerging connected truck data to propose scalable methods to evaluate the impact of a rest area closure on truck parking trends on nearby interstate entry and exit ramps presented through a case study on Interstate 70 in east central Indiana (**Figure 2**). Although it was expected that this would result in increased parking by trucks on adjacent ramps, this before, during,

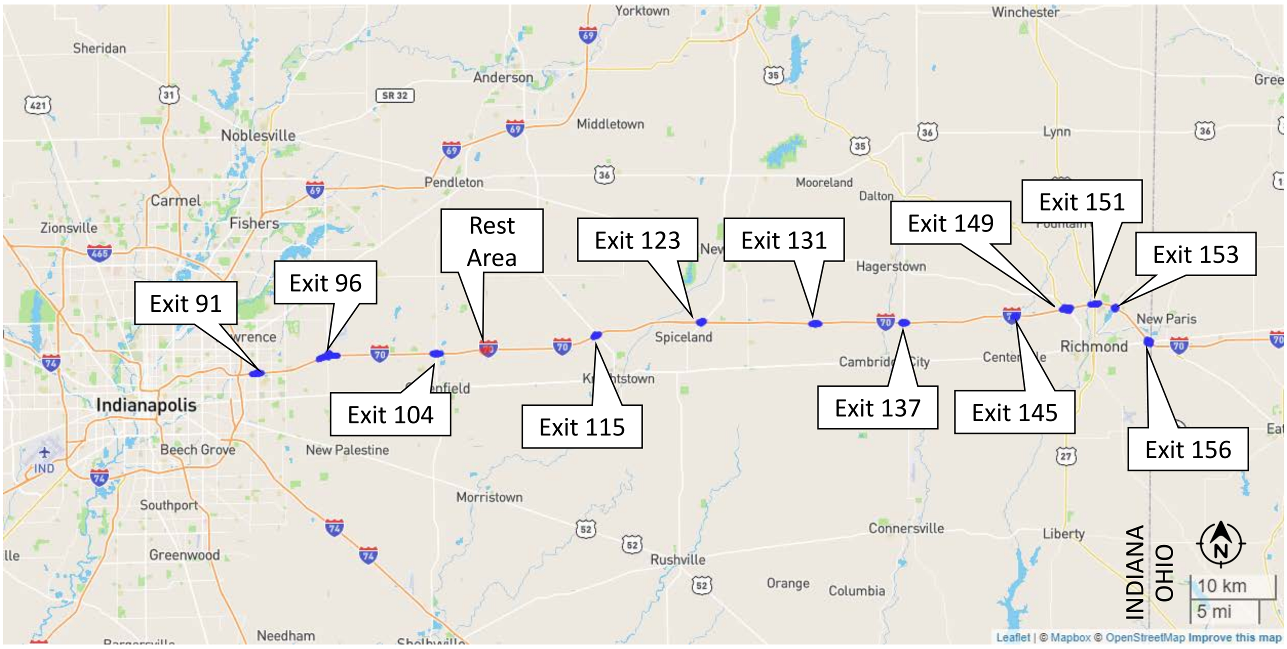


Figure 2. Map showing study location-rest area and nearby exit ramps.

after scenario provides an ideal scenario to evaluate the robustness of these techniques to assess changing parking characteristics of long-haul commercial trucks.

The Greenfield, IN rest area, located around MM 105, between Indianapolis and Ohio was closed for construction during the months of September and October 2022 and provided an opportunity for a before/after assessment of truck parking patterns using CV data. This research compares the truck parking activity on exit ramps between Exit 91 and Exit 156 (**Figure 2**) across three study periods:

- Before: Period before the rest area was closed
- During: Period during the closure
- After: Period after the rest area reopened

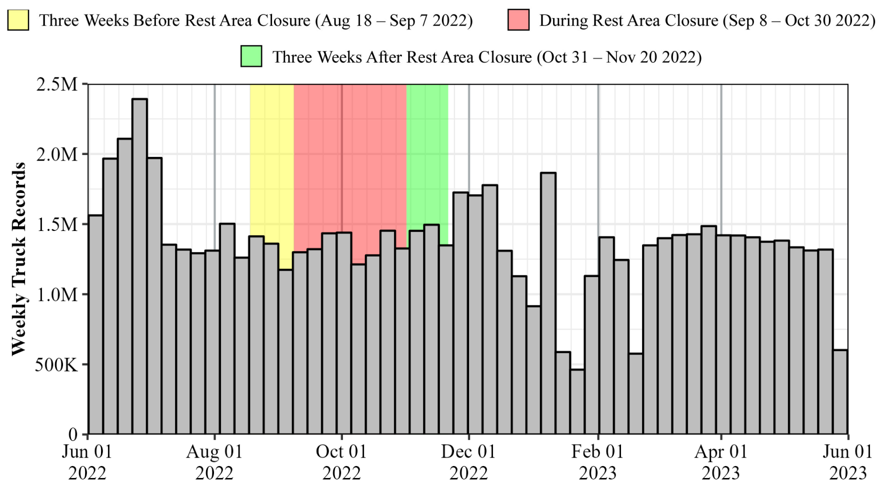
A methodology to identify and estimate parking sessions from connected truck data is first presented followed by analysis and visualizations that compare the impact of rest area closure on ramp parking and the temporospatial parking patterns across the three study periods.

4. Connected Truck Data

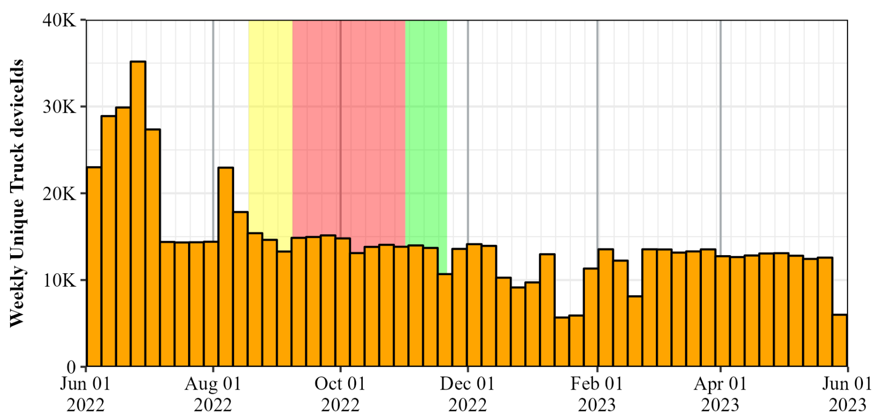
Several third-party commercial vendors now supply anonymized connected truck trajectory data consisting of a unique vehicle identifier, speed, heading and timestamp along with the geo-positional coordinates. The anonymized data, available on a reporting frequency of mostly 10 s, is collected directly from the truck or using a third-party telematics device or smartphone app. Studies have shown that the market penetration rate for this connected truck sample ranges from 1% to 4% [27].

Over 81 million connected truck records along the study corridor were generated between June 2022 and 2023. **Figure 3** provides an overview of the weekly aggregated total truck data records (**Figure 3(a)**) and unique anonymized truck identifiers (**Figure 3(b)**) from the available data. Data preprocessing was first carried out to check for duplicate and incomplete records. There were several data quality (duplicate records) issues reported between June 1 and Aug 17, 2022, and hence, it was decided to begin the data analysis from Aug 18, 2022. As seen, there is a considerable spike in the total records and unique truck identifiers between June and August, which was reported by the data provider as an erroneous feed. To exclude this erroneous data and for ease of normalization purposes, the analysis duration was limited to the below periods for the three study intervals:

- Before: Period before the rest area was closed (21 days from Aug 18 to Sep 7, 2022).
- During: Period during the closure (53 days Sep 8 - Oct 30, 2022).
- After: Period after the rest area reopened (21 days Oct 31 - Nov 20, 2022).



(a)



(b)

Figure 3. Weekly connected truck records. (a) Total records; (b) Unique truck identifiers.

The final data set covering the above three periods along the study corridor included nearly 21 million connected truck records.

5. Methodology

For the rest area, a geofence in each direction is established along the perimeter of the rest area (Figure 4(a)). For every connected truck trip entering and leaving the rest area, the duration of stay is estimated from the first record of entry and last record before exit. Sessions with duration of at least 30 minutes or more are then recorded as a parking session.

Similarly for the study locations' ramps, a geofence (roughly 100 ft wide) is established along the ramp. For exit ramps, the geofence begins from the exit ramp separation and ends at the next intersection. For entry ramps, the geofence begins from the intersection and ends at the point where the ramp merges with the interstate. Similar to the rest area, the duration is estimated for all connected trucks entering and leaving each ramp. If the duration spent by a trip exceeds 30 minutes on the ramp, it is considered as a parking session. Any sessions greater than 8 hours are treated as outliers. A minimum threshold of 30 minutes removes short stops from traffic control devices and/or quick maintenance checks.

(a)

(b)

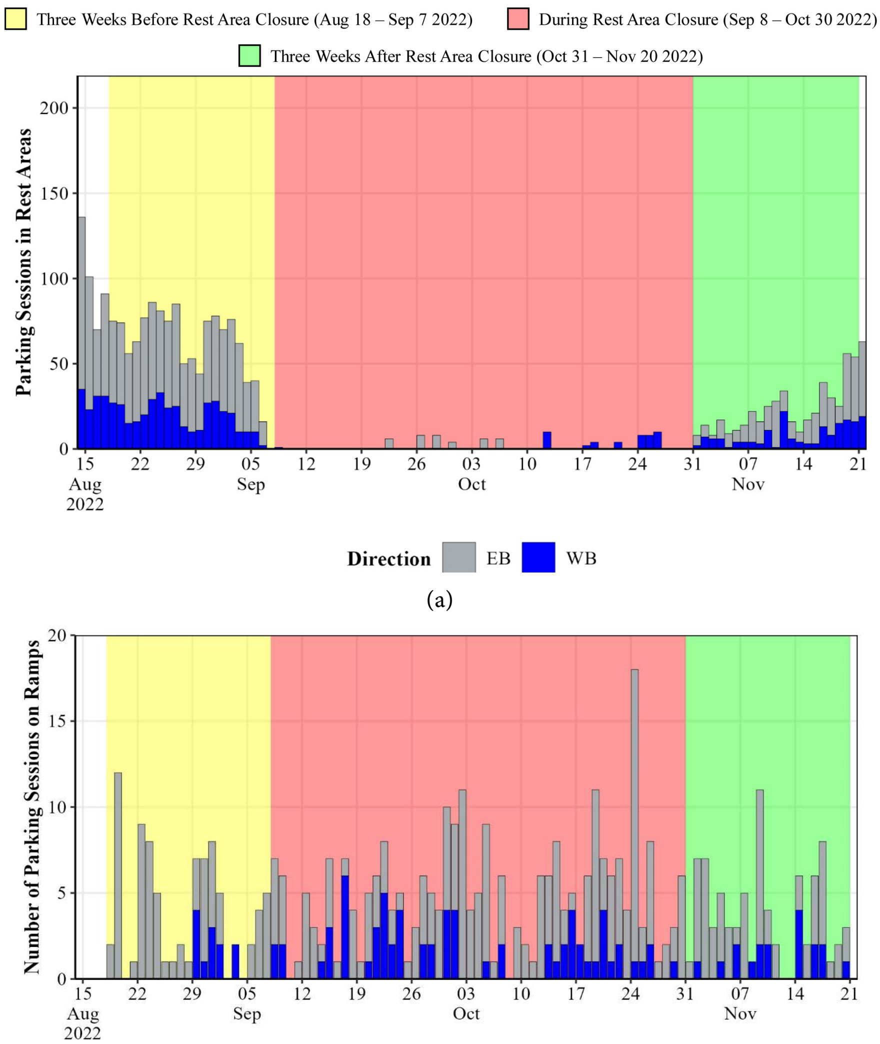
Figure 4. Methodology for identifying and estimating truck parking sessions. (a) Rest area; (b) Ramps.

Additionally, FMCSA mandates a 30-minute driving break after driving for a period of 8 cumulative hours without any interruption [3]. **Figure 4(b)** shows an example of a truck parking session identified on the entry ramp from SR 109 to I-70 at Exit 115. The red polygons illustrate the geofenced region along the ramp and the black dots denote the geo-positional data from a connected truck. The truck enters the ramp around 4 AM (callout i) and leaves around 8 AM (callout ii) on the same day, resulting in a parking session of 4 hours.

6. Comparison of Parking Sessions at Rest Area and Ramps

6.1. Overall Daily Utilization

Figure 5 provides a temporal overview of the parking sessions recorded per day at the rest area and all ramps by direction during the three study periods. Across the three study periods, there were over 1830 and 425 parking sessions at the rest area and ramps, respectively (**Table 1**).



(a)

(b)

Figure 5. Daily parking sessions. (a) Rest area; (b) Exit ramps.

Table 1. Parking sessions across the three study intervals.

Location	Before Closure		During Closure		After Closure	
	Total	Average	Total	Average	Total	Average
Rest Area						
Eastbound	896	42.7	38	0.7	318	15.1
Westbound	379	18	47	0.9	156	7.4
Total	1275	60.7	85	1.6	474	22.5
Ramps						
Eastbound	70	3.3	196	3.7	62	2.6
Westbound	12	0.6	69	1.3	18	0.9
Total	82	3.9	265	5.0	80	3.5

In the "Before" period at rest areas, the maximum recorded activity is around 75 parking sessions per day, however this reduced to around 50 sessions in the "After" period (Figure 5(a)). During the closure, there is a stark reduction in the parking sessions as expected. However, there are still a few sessions recorded in the "During" period which could mainly be due to trucks parking on the entry/exit ramps of the rest area. In the "After" period, parking at the rest area decreased by 10% compared to the "Before" period, which indicates that few trucks continued to park at other truck stops or rest areas in nearby states.

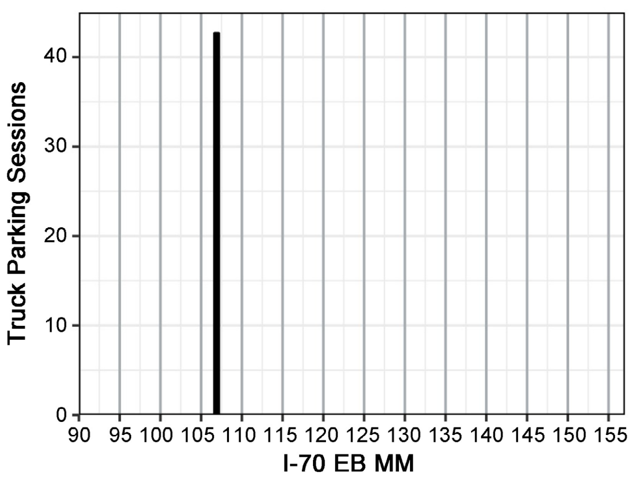
Figure 5(b) shows the total parking sessions on the ramps across all the exits in this study. While the maximum number of sessions peaked around 12 sessions/day in the "Before" and "After" periods, the maximum sessions in the "During" period rose to 18 sessions/day, thus highlighting the additional parking on ramps due to the limited availability during closure. On average, the number of parking sessions per day went up from 3.9 to 5, resulting in a 28% increase in the "During" period compared to the "Before" period (Table 1).

Aggregating by direction, roughly 77% of the sessions are found on Eastbound (EB) ramps and remaining 23% on Westbound (WB) ramps. Due to the low sample size in WB direction, further analysis in this study is limited to the EB direction.

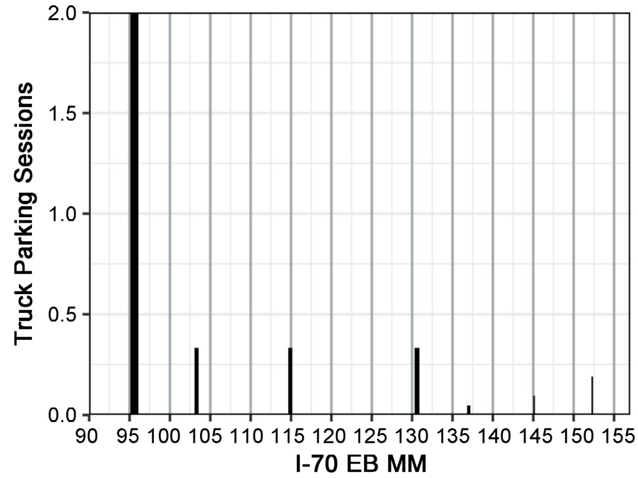
6.2. Impact of Rest Area Closure on Individual Exits

Figure 6 shows a bar plot comparing the normalized truck parking sessions per day between the rest area and exit ramps across the three study periods in the EB direction. The line thickness for exit ramps in Figure 6(b), Figure 6(d) and Figure 6(f) vary by the length of the ramps—the longer the ramp, the thicker the bar.

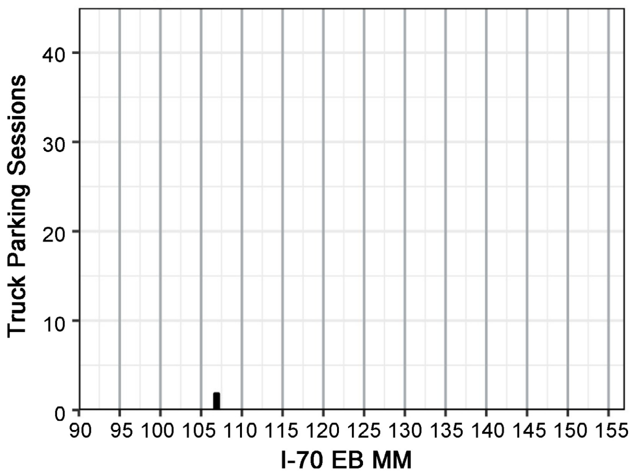
In the "Before" period, there are over 40 sessions per day at the rest area (Figure 6(a)), whereas there are less than 0.5 sessions per day across the exit ramps (Figure 6(b)), apart from Exit 96 which will be discussed in the next section.



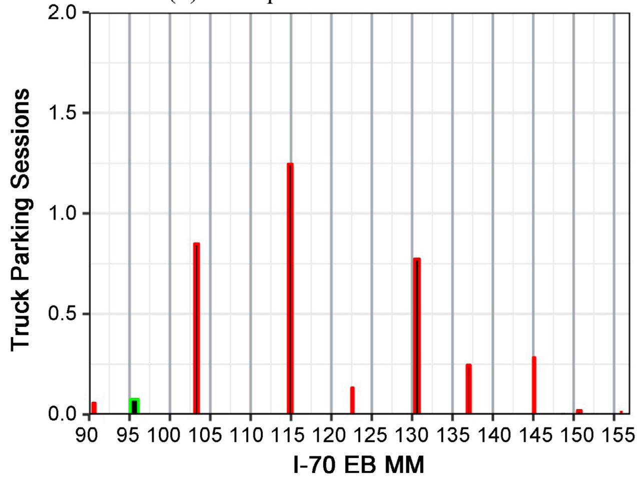
(a) Rest Area – Before Closure



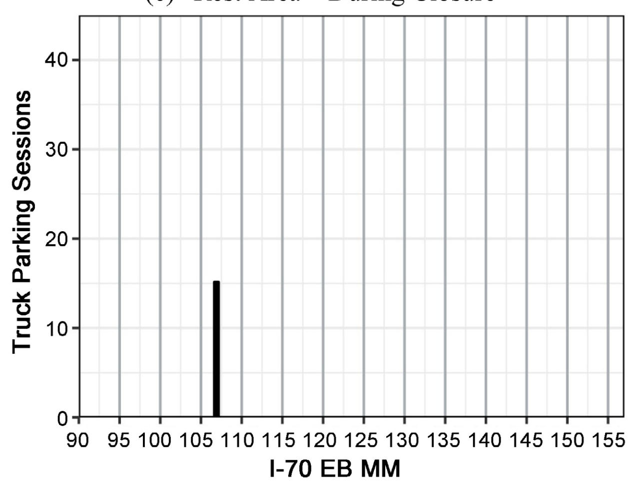
(b) Ramps – Before Closure



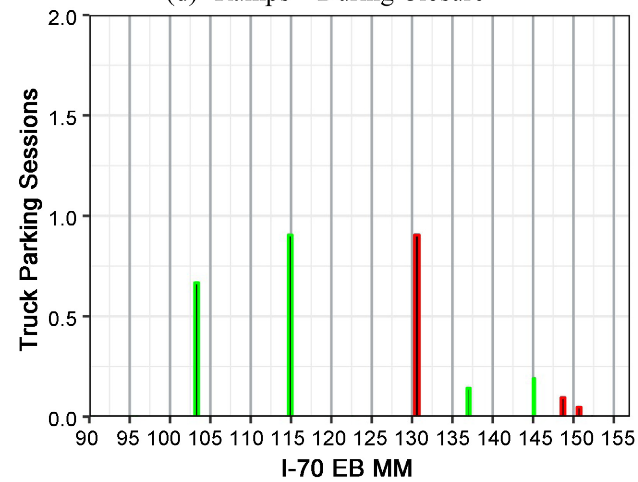
(c) Rest Area – During Closure



(d) Ramps – During Closure



(e) Rest Area – After Reopening



(f) Ramps – After Reopening

Figure 6. Normalized truck parking sessions per day before, during and after closure of rest area—EB.

In the "During" period, parking sessions plummeted at the rest area (**Figure 6(c)**) as expected, however the number of sessions on the ramps increased substantially. Compared to **Figure 6(b)**, an increase in the number of sessions is highlighted by red and a drop in sessions by green, in Figure 6(d). Compared to the "Before" period, there is around 1.3 to 4 times increase in the number of parking sessions per day on exit ramps during the closure (Table 2). Impact of the closure is only estimated for exit ramps with some activity in the "Before" period.

In the "After" period when the rest area reopened, the parking sessions at the rest area goes up but is still lesser than the "Before" period, around one-third of the "Before" period. The parking sessions on the exit ramps also drops compared to the "During" period (Figure 6(f)), except for Exit 131 where the sessions increased by 0.1 times (Table 2). Compared to the "Before" period, parking sessions increased on all exit ramps except for Exits 96 and 153.

Table 2 replicates Figure 6 with additional information comparing the impact or variation in parking sessions across the three study periods. Impact is only highlighted for cases where there are a non-zero number of sessions during the base period.

There are several key takeaways from Figure 6 and Table 2:

- It is interesting to note that there are some parking activities on the exit ramps even before the rest area closure (Figure 6(b)).
- Exit 137 recorded the highest impact (around 4x times increase) during the closure. On further investigation, it was found that this Exit serves a nearby distribution center (Figure 7 callout i). It is possible that trucks going to this distribution center may have used the rest area to stage themselves prior to scheduled delivery or pickup times before the closure. During the closure these trucks may have resorted to using this exit ramp for staging purposes.

Table 2. Normalized truck parking sessions per day—EB.

Location	Before Closure	During Closure		After Reopening		
		Sessions	Impact (vs Before)	Sessions	Impact	
					vs Before	vs During
Exit 91	0.00	0.06	-	0.00	-	-
Exit 96	2.00	0.08	-	0.00	−1.00x	−1.0x
Exit 104	0.33	0.85	1.5x	0.67	1x	−0.2x
Rest Area	42.67	0.72	−0.98x	15.14	−0.6x	20x
Exit 115	0.33	1.25	2.7x	0.90	1.7x	−0.2x
Exit 123	0.00	0.13	-	0.00	-	−1.0x
Exit 131	0.33	0.77	1.3x	0.90	1.7x	0.1x
Exit 137	0.05	0.25	4.x	0.14	1.8x	−0.4x
Exit 145	0.10	0.28	1.8x	0.19	0.9x	−0.3x
Exit 149	0.00	0.00	-	0.10	-	-
Exit 151	0.00	0.02	-	0.05	-	1.5x
Exit 153	0.19	0.00	−1.0x	0.00	−1x	-
Exit 156	0.00	0.02	-	0.00	-	−1.0x

Figure 7. Distribution facility (callout i) near Exit 137.

- Excluding the above exit, the next highest impact (2.7x) is seen on Exit 115 which is right after the rest area (MM 105). This is intuitive as trucks try to find the next available parking as soon as they understand that the rest area is closed. Collectively, across all exits, there is an impact of 1.5 to 2.7 times increase in the number of sessions during the closure.
- After the rest area opened, the parking activity increased on most of the ramps (compared to "Before") indicating a change in driver behavior. Although the rest area closure was temporary, the resulting driver behavior appears to have had a more significant impact on the shift in parking patterns from rest areas to exit ramps.

6.3. Investigation of Truck Parking Session Spike at I-70 EB Exit 96

Figure 8 illustrates the parking sessions (blue dots) on Exit 96 between Jul and Dec 2022. There are no parking sessions before Jul 20 (Figure 8(a)), but during the period between Jul 20 and Sep 15 there are roughly 90 sessions on the ramps (Figure 8(b)). There was construction activity during this period that resulted in the construction trucks being parked on the closed ramps, eventually leading to the spike in Figure 6(b). The ramps were opened after Sep 16 and conditions returned to normal with very few parking sessions (Figure 8(c)) possibly due to the rest area being closed during this period. This example shows how connected truck data helps to derive additional insights on outliers and extreme value cases which may not have been possible from traditional data collection sources and efforts.

6.4. Temporal Patterns

Figure 9 shows the aggregated truck parking activity in the EB direction on rest area and ramps by time of day. The total number of active sessions are aggregated over one-minute intervals and normalized by the total sessions across the

(a)

(b)

(c)

Figure 8. Impact of construction on parking sessions at I-70 EB Exit 96. (a) July 1-19, 2022—Ramps open; (b) July 20-Sep 15, 2022—Ramps closed; (c) Sep 16-Dec 31, 2022—Ramps open after construction.

three study periods to develop this visualization.

For rest areas, in the "Before" period, there is continued activity throughout the day with increased activity during nighttime hours (**Figure 9(a)**). The peak activity occurs between 1 PM and 4 PM (callout i) which indicates that short duration parking trucks utilized the rest area more than those parked for longer duration. In the "During" period, there is almost no activity throughout the day (**Figure 9(b)**). There is some minor activity between 4 AM and 6 AM (callout ii), which could be trucks parking on the rest area ramps (**Figure 10**). In the "After" period, activity picks up but is much lower than the "Before" period. At peak, while the "Before" period recorded more than 6 active sessions per minute per

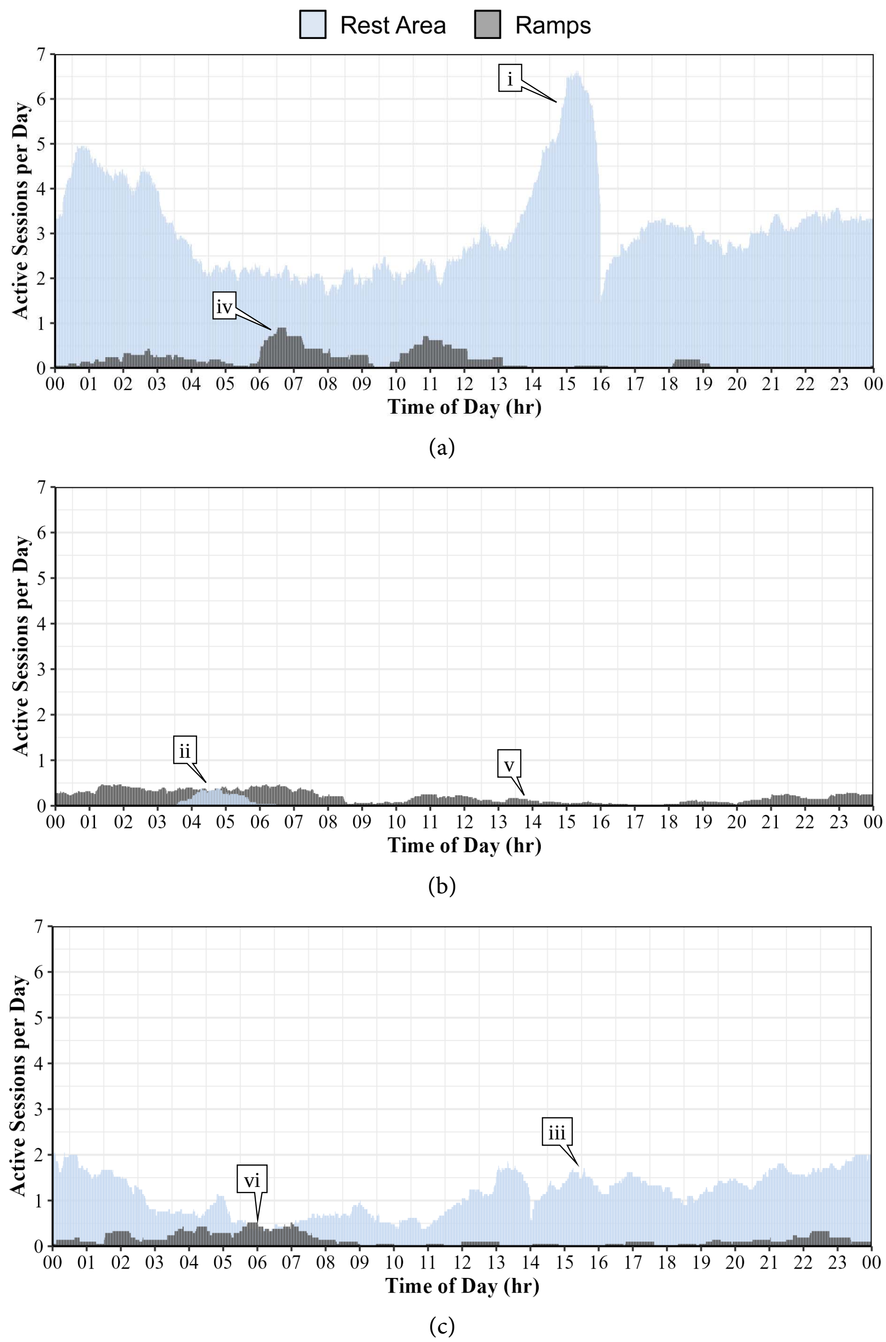


Figure 9. Temporal variation of truck parking on ramps—EB. (a) Before rest area closure; (b) During rest area closure; (c) After rest area reopening.

day, the "After" period dropped to less than 2 sessions per minute per day (callout iii). There is also a change in the pattern or parking behavior with no considerable peaks in the afternoon. This could mean that those short duration trucks continue to park elsewhere even after the reopening of the rest area.

For exit ramps, in the "Before" period (**Figure 9(a)**), there is intermittent activity throughout the day. Overnight parking begins around midnight and continues until 5 AM. Major activity occurs from 6 AM-9 AM and from 10 AM-1

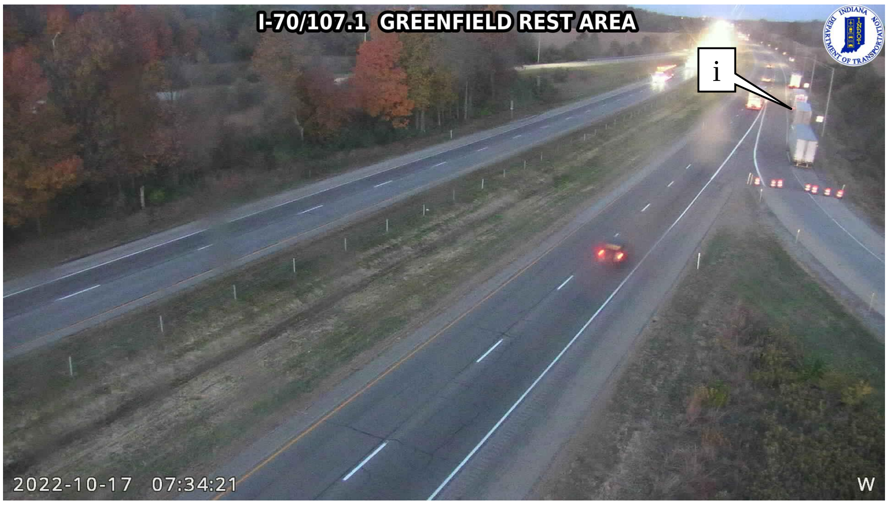


Figure 10. Trucks parked on entry ramp near rest area during rest area closure.

PM with peak between 6 AM and 7 AM (callout iv). During the closure (**Figure 9(b)**), there is sustained activity overnight beginning from 8 PM and continuing until 9 AM. Compared to the "Before" period, there is slight increase in activity between 1 PM and 5 PM (callout v), which could be the short duration trucks that used to park in the rest area. In the "After" period (**Figure 9(c)**), the trend is similar to the "During" period, except for a drop in activity during the mid-day/afternoon time. Compared to the "Before" period there is an increase in the overnight activity from 7 PM to 8 AM, with peaking occurring between 2 AM and 8 AM (callout vi). This indicates that some trucks continued to utilize the ramps even after the rest area opened.

6.5. Session Duration

Figure 11 compares the cumulative frequency distribution of the session duration across the three study periods. In the EB direction (**Figure 11**), the median and maximum duration in the "Before" period is around 1hr (callout i) and 3 hrs (callout ii), respectively. In the "During" period when the rest area was closed, the median duration is slightly lower around 0.75 hrs, however the maximum duration went up to nearly 8 hrs (callout iii) with more than 10% of the sessions exceeding 3 hrs. The "After" period also saw an increase with maximum duration around 4.5 hours (callout iv).

7. Conclusions

This research uses connected truck trajectory data to study the impact of an interstate rest area closure on truck parking trends on nearby entry and exit ramps. Nearly 21 million connected truck records on interstate I-70 between Indianapolis and the Indiana-Ohio border were analyzed between September and November 2022. A methodology is first presented to identify and estimate truck parking sessions from the raw connected truck trajectories (**Figure 4**). Spatiotemporal analysis and graphical visualizations were developed to study and

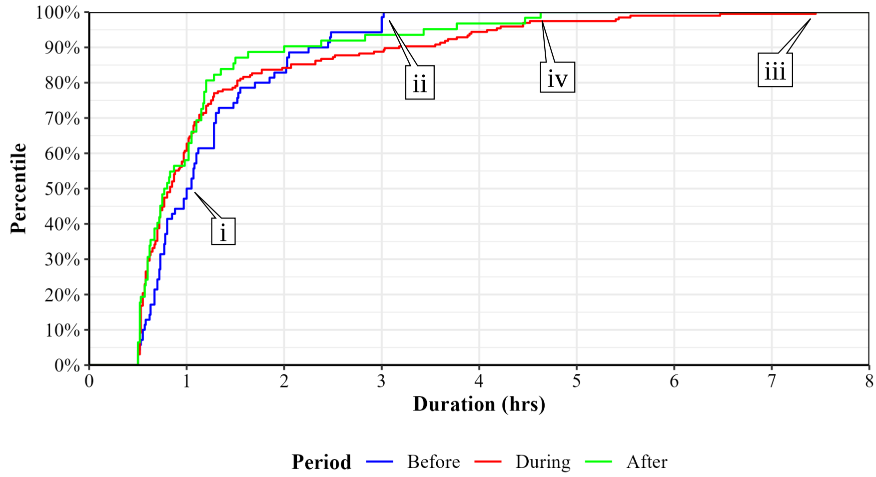


Figure 11. CFD of truck parking duration on EB ramps.

compare the impact between three periods—before rest area closure, during closure and after rest area reopening.

Over 1830 and 425 parking sessions were recorded at the rest area and ramps, respectively during the study duration. Across all exit and entry ramps, there was a 28% average increase in daily parking sessions during the closure (Figure 5, Table 1). Further analysis on individual exits showed an impact of 1.3 to 4 times increase in the number of parking sessions per day during the closure, with the two closest exits to the rest area recording an impact of 1.5x and 2.7x (Figure 6). Temporal analysis of parking sessions on ramps showed sustained and longer duration during the closure compared to short sessions before the closure (Figure 9, Figure 11).

While there were two distinct peaks in parking activity at the rest area before closure (during overnight hours, and between 1 PM and 4 PM), the period after reopening had substantially reduced activity (both during day and night) without any major peaks (Figure 9). However, ramp parking activity slightly increased between the before and after period, especially during overnight hours, indicating that some trucks continued to utilize the ramps even after the rest area re-opened. Although it was expected that this would result in increased parking by trucks on adjacent ramps, this before, during, after scenario provided an ideal scenario to evaluate the robustness of these techniques to assess changing parking characteristics of long-haul commercial trucks.

Ensuring adequate parking spaces for long haul commercial trucks is an important objective for state and local agencies. Although there are several ITS resources for monitoring and providing information on the availability of spaces on rest areas and private truck stops, it is nearly impossible to track the parking trends of trucks on exit and entry ramps. There are also very limited resources available for enforcing illegal parking on the ramps. The results from this study will be helpful for agencies to quantify the impact of adjacent ramp parking during the closure of a heavily utilized rest area. The framework presented in this study can also be scaled across the state or nation to systematically identify ramps and other roadside areas with illegal truck parking that could pose an inherent safety risk to travelling motorists as well as to commercial vehicle drivers themselves.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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