

Utilizing Connected Vehicle Data to Identify Impacts of Congestion on Adjacent Agencies

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Abstract

Most state agencies have good practices for monitoring congestion on roadways within their jurisdiction. Many urbanized areas span state boundaries, where incidents, work zones, and congestion often impact neighboring states or municipalities. States with urbanized borders that experience congestion often develop informal communication procedures and occasionally share a few traffic management cameras. However, system integration to share between adjacent states can be challenging, particularly for work zones and incidents. Commercial connected vehicle data (CV) provides real-time probes for corridors and can be used to monitor traffic data either within a state or across the border into an adjacent state with no requirement for institutional interfaces. For example, Indiana has 15 interstate crossings into four different states. As a matter of practice, Indiana purchases connected vehicle data that extends 10 miles into all neighboring states. This provides an ability to monitor work zones, incidents, and re-occurring congestion in adjacent states that may impact Indiana, as well as understanding when Indiana freeway congestion impacts neighboring states. This paper presents case studies that explain how cross border queuing can be monitored and summarized over a year for the I-94, I-90, I-70, I-69, I-65, I-64, I-275 and I-265 Indiana Interstates. The inbound IL to IN segment of I-94 had the largest median hours of queuing with 69.1 hours per week. The outbound IN to KY segment of I-275 departing Indiana had the largest median hours of queuing with 19.5 hours per week.

Keywords

Connected Vehicle, Border Queueing, Freeway, Congestion, Mobility

1. Introduction

Interstate queuing is a concern for all agencies. Transportation agencies typically

focus on managing roadways within their jurisdiction. However, traffic congestion can often extend beyond state borders and impact adjacent states. Typical causes include work zones, toll plazas, crashes and facilities that are over capacity. For effective management it is important to have quantitative data on the location, direction, severity, and cause of cross-border queuing. Tracking root cause and location of congestion at borders is important for not only planning future capital projects, but also from an operational and regional mobility perspective. In fact, crash rates have been reported to increase by approximately 24 times when unexpected queuing is encountered on interstate routes [1]. To place this discussion into visual context, **Figure 1** and **Figure 2** are examples of I-94 Eastbound (EB) and I-94 Westbound (WB) queuing across the Indiana-Illinois border, respectively.



Figure 1. I-94 eastbound border queuing at MM 0 from Illinois to Indiana-Thursday, July 25th, 2024.

Figure 1 is an Intelligent Transportation System (ITS) camera view of eastbound congestion on I-94 at the state line from Illinois into Indiana, while the westbound side of the road is shown to be clear in terms of traffic congestion. This example is from Thursday, July 25th, 2024, where the observed roadway capture was taken at 13:52 EST at the 0-mile marker.

Similarly, **Figure 2** is a camera view of congestion westbound on I-94 at the state line from Indiana into Illinois, while the eastbound side of the road is shown to be clear in terms of traffic congestion. This example is from Wednesday, July 24th, 2024, where the observed roadway capture was taken at 14:34 EST at the 0-mile marker.

In general, regardless of the congestion extending beyond a municipality, state, or country, the administrative structure of most transportation agencies does not provide comprehensive visibility into adjacent jurisdictions, nor do those agencies routinely monitor their impact on adjacent entities. In some cases, metropolitan planning organizations have limited programs for coordinating projects, but at a

tactical level, there is limited day-to-day sharing of real-time traffic condition data. The subsequent sections discuss the opportunity to use connected vehicle data for improving coordination of congestion monitoring with adjacent agencies.

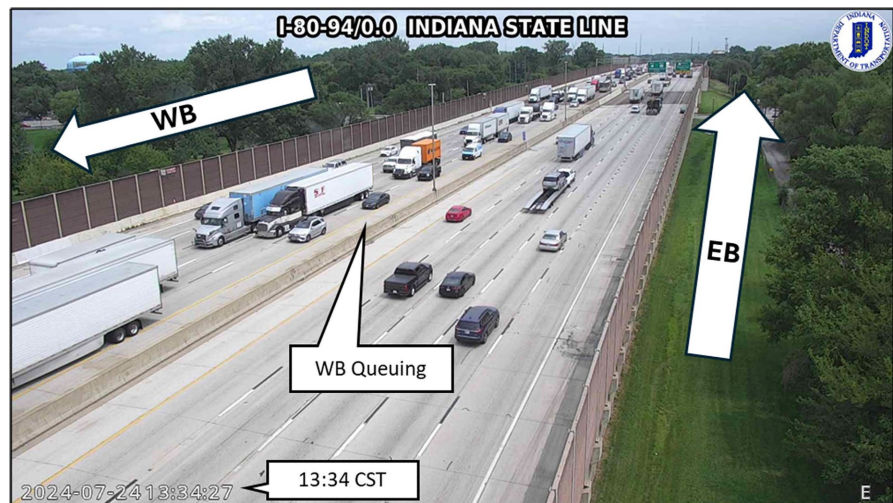


Figure 2. I-94 westbound border queuing at mm 0 from Indiana to Illinois-Wednesday, July 24th, 2024.

2. Objective

Although cross-border queuing is clearly visible in **Figure 1** and **Figure 2**, having operators visually monitoring cameras pointed at border crossings and recording time and duration of queuing events does not scale. The objective of this paper is to develop procedures to use connected vehicle data to monitor speeds in segments immediately adjacent to the border and identify time, duration, and severity of these cross-border queues. Using detailed data, a series of graphics are proposed that provide day by day summaries that aggregate well over a year. This provides a tool for tracking emerging new problems, as well as tracking re-occurring problems to identify trends and provide input into capital investment decisions. The remainder of this paper focuses on scalable techniques to use connected vehicle data to monitor cross-border interstate queuing. The annual timeframe of this study is July 1st, 2024, to June 30th, 2025.

Literature Review

Most past studies have examined negative impacts of traffic congestion, and a few studies have examined cross-border congestion. These studies vary in their data source, geographic focus, as well as the quantification of their results and findings. In 2021, the study “Traffic congestion, transportation policies, and the performance of first responders” [2] covers adverse effects of traffic on emergency response times in U.S. metro areas using frequent connected vehicle data, however, the scope of this study does not cover traffic queues across borders. A 2010 study, “Measuring Cross-Border Travel Times for Freight” examined truck crossing travel times across the San Diego, California border from the United States into

Mexico. In 2010, vehicle telematics was still maturing the authors reported. The truck GPS data was quite sparse and infrequent. A 2022 border study investigated cross-border queuing at the Texas-Mexico border [3] which examined the potential of market-available connected vehicle waypoint data for estimating border crossing time and queuing, but does not investigate causes of cross-border queuing. Internationally this has also been a concern and a 2019 study of European border crossing delay examined impact of policies [4]. However, because the paper was policy focused, it does not actually quantify or mathematically analyze these effects except by estimating a Cross-border Transport Permeability Index.

When investigating cross-border queuing, identifying the cause of the congestion is a major concern. There are numerous factors that influence traffic accumulation. It's been shown that congestion often occurs from urban areas [5]-[8] which suggests that Indiana borders with major cities would experience high-volume congestion. Locations with work zones or lane restrictions typically result in higher congestion [9]-[11]. Finally, seasonal traffic volumes and weather can be significant factors in congestion, as well [12] [13].

3. Methods

3.1. Using Connected Vehicle Data to Systematically Monitor Border Queues

Approximately 500 billion connected vehicle records are produced every month in the US. These records are available in near real-time and with a frequency of approximately 3 seconds. On average, approximately 1 in 20 to 1 in 25 vehicles on the roadways produce this information that can be commercially purchased in either a raw form [14], or a summarized form [15].

To realize the benefits of this data, it is particularly important to ensure both the data and underlying geographic information systems (GIS) network extend into border states so an integrated analysis can be conducted. This allows agencies to monitor

- Activities across the border that may impact them
- Activities within their border that may impact neighboring jurisdictions

Indiana purchases connected vehicle data that extends roughly 10 miles beyond all borders to ensure full visibility on traffic conditions within the state as well as immediately adjacent to its borders.

3.2. Data Preparation

This study used a GIS network that is composed of 0.1-mile segments to aggregate CV data into 1 minute speed summaries. The analysis looked at 26 border crossings into and from Illinois, Ohio, Kentucky, and Michigan, on 8 enumerated interstates. Across the 26 border crossings, there were 260 0.1-mile segments that were analyzed over a 12-month period from July of 2024 to June of 2025.

For this study, we analyzed approximately 260 segments that were 0.1 mile long at 13 locations. This corresponded to approximately 45,477,706 one-minute re-

coveries over 12 months. In total, approximately 185,037,945 waypoints were used to tabulate those one-minute, 0.1-mile segment cords.

3.3. Case Study of the Illinois-Indiana Border Analysis on One Day

This section presents an example that illustrates how connected vehicle data mapped to geographic segments, nominally 0.1 mile in length, can be processed to provide quantitative summaries that can be quickly visualized.

Figure 3 shows a sample traffic speed heatmap of I-94 EB across the Illinois-to-Indiana border. This figure shows the speeds of the CVs traveling through this segment of the interstate, represented as colors. The seven colors used are purple, red, dark orange, light orange, yellow, dark green, and light green which corresponds to speed ranges of 0 to 14, 15 to 24, 25 to 34, 45 to 54, 55 to 64, and 65 and above miles per hour, respectively. The heatmap's vertical axis shows linear-referenced mile marker locations and the horizontal axis shows time of day, which allows interpretation of speed by location and time [16]. You can identify the first signs of queuing in Indiana starting at approximately 10:30 EST and by 11:00 EST that queue has extended into Illinois. That queueing does not clear until 18:30 EST. Also, one can observe the queuing at 10:30 EST starts around MM 1.5 and additional queuing in Indiana begins around 12:30 EST at MM 5.

Although these graphics are intuitive, an approximate value for duration and location can be visually extracted by inspection. This information is more effective when one views this as a table of data in two dimensions:

- Time, with a 1-minute resolution.
- Space, with a 0.1-mile resolution.

Using data in that format, one can construct a database query that extracts the time periods where speeds are below 45 mph on each side of the border, a commonly used threshold for freeway congestion. In the event of discontinuous border queueing throughout the day, those time periods can be summed up.

When tabulating the queueing, it is important to associate it with the direction of travel, as every interstate border crossing includes two directions. A visual representation of Eastbound queueing can be observed in **Figure 3**, a sample heatmap of I-94 EB across the Illinois-to-Indiana border. In this figure, the analysis region was observed half a mile before and after the border. From the large range of data over each interstate, a query was executed to focus on queuing across state borders, requiring a quantitative definition of cross-border queuing. Cross border queuing is evaluated in 1-minute bins where a query analyzes a mile-long segment, half of a mile on each side of the border. Over this one-mile segment, every minute where 70% of the ten 0.1-mile segments are experiencing an aggregated mean speed under 45 miles per hour, is classified as experiencing queuing. Although this 70% threshold was determined empirically, quality control checks have found this to be very robust at identifying periods with queuing. Different agencies are open to defining their preferred thresholds. The number of bins is then summed up over a day to quantify the duration of cross border queuing.

Past research shows that a speed of 45mph is an appropriate threshold that is considered congestion for a segment of an Interstate [17]. Past research shows the application of the 85th percentile speed on roadway speed limit adaptation [18], however, given the restriction that the data used in this study only covers 5% of vehicles on the roadway, a conservative application of 70% of the cross-border segment was deemed feasible for this study.

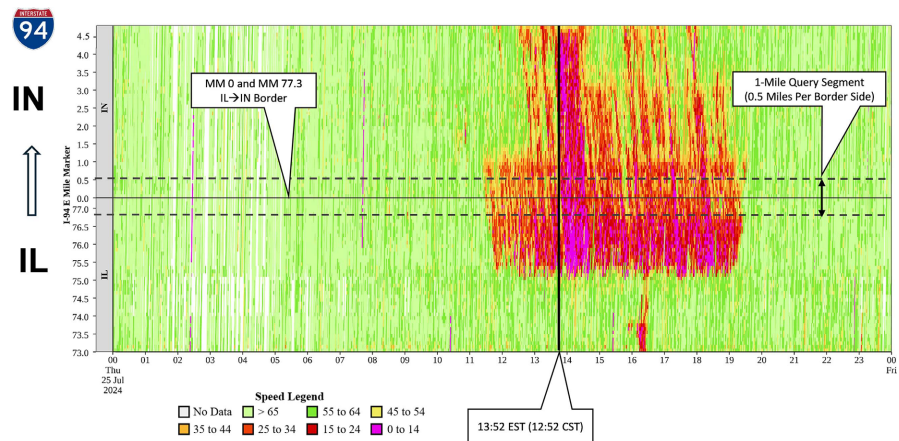


Figure 3. I-94 eastbound cross-border heatmap, Illinois-to-Indiana border-Thursday, July 25th, 2024.

In **Figure 3**, the 1-mile analysis region is noted as the region between the dotted lines. Specifically, this region ranges from Illinois on I-94 East from mile marker 76.8 to mile marker 77.3 and then mile marker 0 in Indiana to mile marker 0.5. This heatmap corresponds to **Figure 1** on July 25th, 2024, at 13:52 EST at the EB border from Illinois into Indiana.

Within the analysis region, from visual inspection, there is apparent queuing from about 10:30 to 18:30 EST, which would be approximately 8 hours of queuing. However, when analyzing CV data, a more precise tabulation can be calculated. In the case of the detailed segment analysis using a database query, some of the speeds within this congestion region vary above and below the 45-mph query threshold. As a result, the border queuing for I-94 EB across the Illinois-to-Indiana border was only 7.3 hours.

In general, database queries tend to produce lower values for estimating the duration of these queuing conditions because the nature of traffic shockwaves tends to result in some speed oscillation. However, the values produced using these techniques are conservative and do an excellent job at systematically identifying days and durations of these cross-border queuing conditions.

3.4. Case Study of the Illinois-Indiana Border Analysis Over One Week

Figure 3 illustrated the concepts on one day, but for this type of analysis, they must be extended to weekly and yearly time periods to provide a comprehensive

analysis of transient (construction) and systematic (toll booths or re-occurring) congestion.

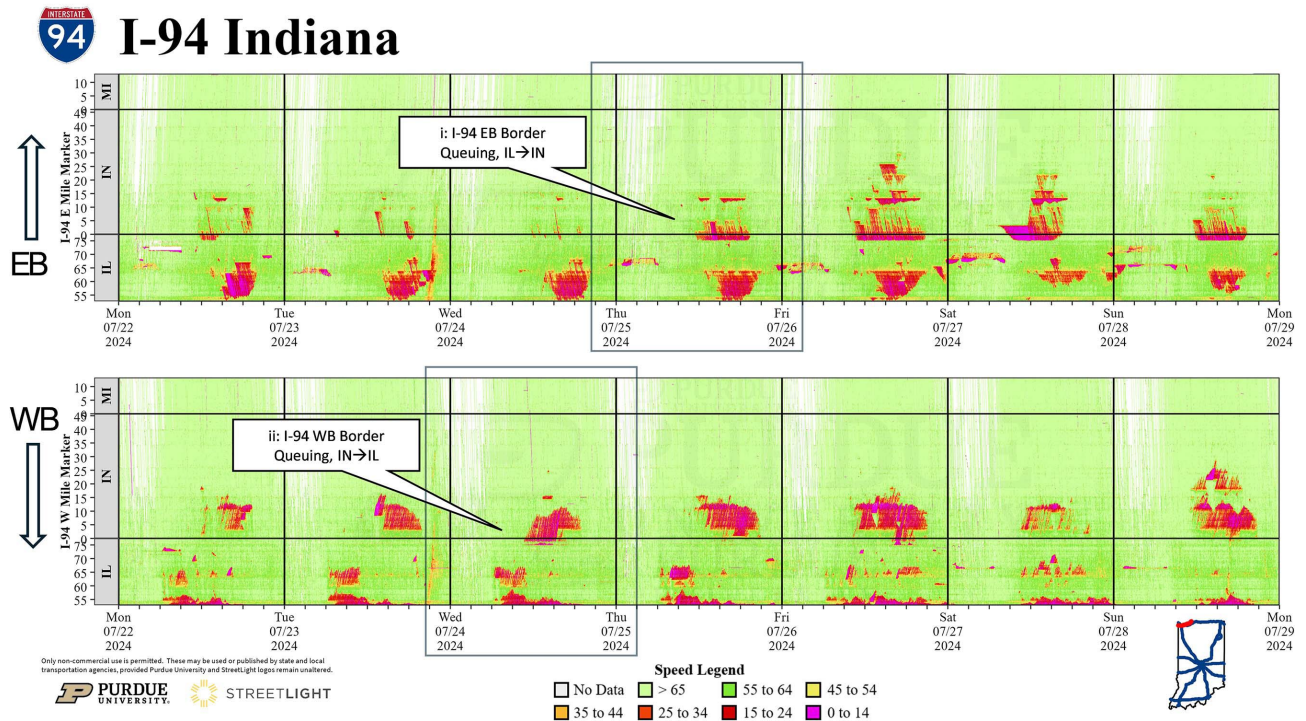


Figure 4. I-94 Indiana weekly border heatmap sample, July 22 to July 28, 2024.

Figure 4 is a weekly border heatmap of I-94 EB in Indiana with 20 miles into Illinois and 10 miles into Michigan that covers the date and time of images shown in Figure 1 (callout a) and Figure 2 (callout ii). On July 25th, 2024, the significant queue appears to be of a magnitude that is ordinary for this border and direction. It can be observed that the latter half of the week for I-94 EB, Illinois-to-Indiana, experiences quite a significant amount of cross-border queuing. In comparison, for the westbound case (callout ii), it is not typical for the queuing to be this severe over the Indiana-Illinois border since Friday is the only other day in the week with significant queuing crossing state lines.

In Table 1, the top row is the I-94 EB border queues from Monday to Sunday, corresponding to Figure 4's two row. Similarly, I-94 WB border queues are on the bottom row of Table 1 and Figure 4. At a quick glance at Table 1, it is obvious that I-94 EB regularly experiences a much higher temporal volume of border queuing whereas I-94 WB does not experience at the severity or frequency that I-94 EB does.

With Table 1, being able to look at each day is very convenient for observing individual border queuing cases, but perhaps more importantly, it illustrates a robust performance measure with a low data footprint that can be further aggregated over a year.

Figure 5 and Figure 6 show an effective method for visualizing border queuing

over a year, providing a visual that presents a whole year’s worth of data by week and characterizes trends. The stacked bar graph reveals what days of the week often experience queuing, what time of the year, and provides an effective overview of the days and duration with operational challenges.

Table 1. I-94 Weekly border queuing sample data across the Indiana-Illinois border.

Border and Direction	Week Sample Data (07/22/2024-07/28/2024)						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Eastbound, IL- > IN (Hours)	2.23	2.10	0.92	7.30	9.85	7.62	7.42
Westbound, IN- > IL (Hours)	0.00	0.05	4.80	0.12	2.27	0.00	0.40

When one looks at the vertical axis scale and compares, **Figure 5** and **Figure 6**, the difference in directional queuing, with much more westbound queuing, is readily apparent. Seasonal impacts are also apparent in **Figure 5**, with queuing decreasing from November of 2024 to February of 2025, and then increases again from March of 2025 to July of 2025 during periods of heavier travel and construction. In **Figure 6**, there is no particular seasonal trend queuing. Rather, there are some significant individual cross-border queues throughout the year likely associated with incidents.

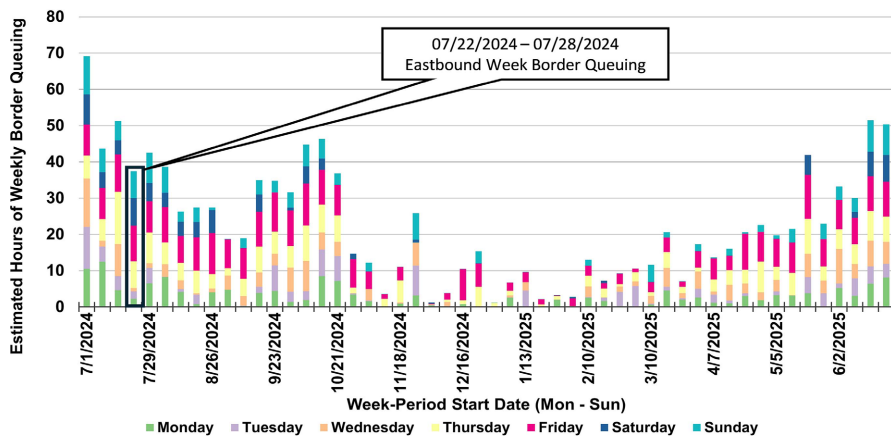


Figure 5. I-94 eastbound weekly border queuing hours across the Indiana-Illinois border.

These annual stacked bar plots have been created for the Indiana I-94, I-90, I-70, I-69, I-65, I-64, I-275, and I-265 interstates which provides insights into queuing between Indiana and Illinois, Ohio, Kentucky, and Michigan corridors. Rather than repeat similar plots for all those interstates and associated border-crossings, the following section presents a method for summarizing each of these border-

crossings so that one can quickly identify systematic re-occurring queuing as well as outliers.

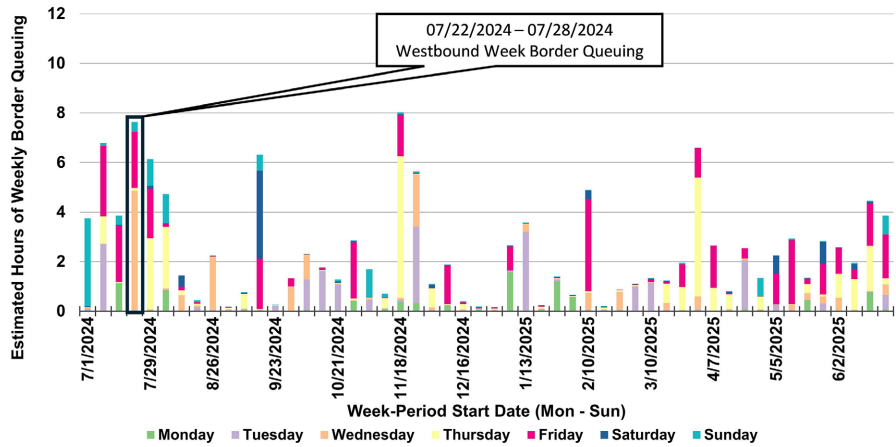


Figure 6. I-94 westbound weekly border queuing hours across the Indiana-Illinois border.

4. Results

Systematically Monitoring All Borders Interface Points

The stacked bar plots from **Figure 5** and **Figure 6** are useful for comparing small samples of interstates, however looking at a larger quantity of interstate queuing would be tedious using the stacked bar plots alone. **Figure 7** is a box and whisker plot showing interstate border queuing characteristics based on a year’s worth of data.

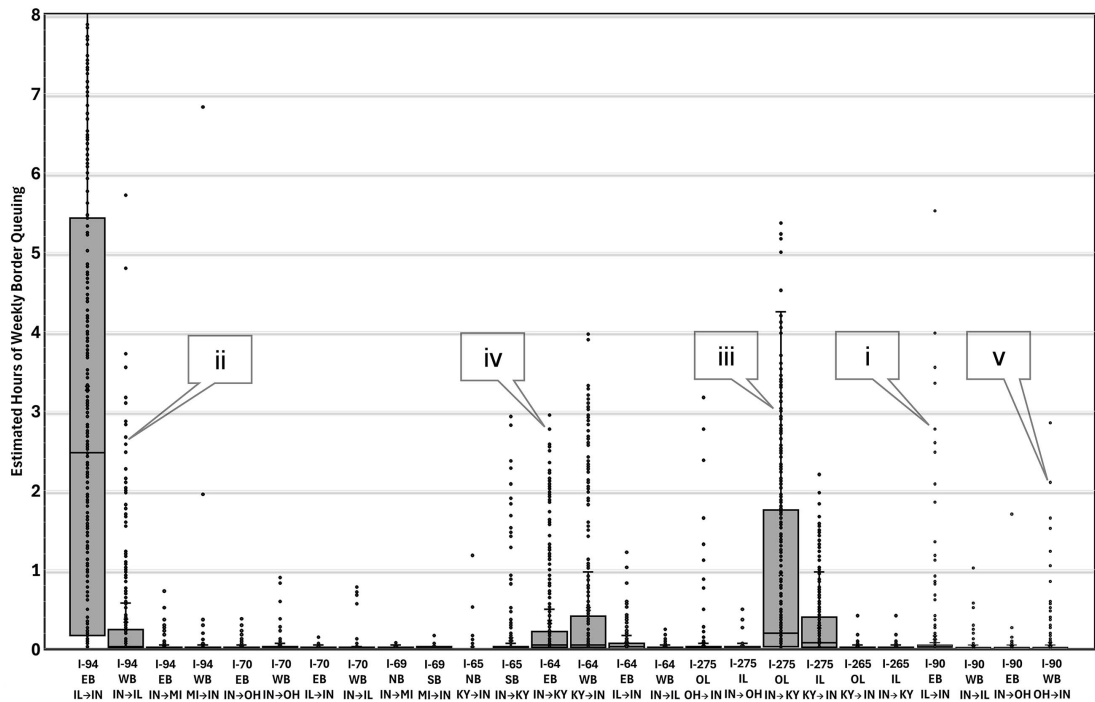


Figure 7. Indiana border queuing accumulation by interstate, direction, and border.

On this plot, every point represents the duration of queuing for one day during the year. The bottom whisker is the minimum, the bottom line of the bar is the 25th percentile queue time, the middle line of the bar is the 50th percentile queue time (or the median), the top line of the bar is the 75th percentile queue time, the top of the whisker is the maximum queue time, and the dots outside these bounds are considered outliers. As can be seen, I-94 EB from Illinois into Indiana has the most significant border queuing, accompanied by I-64's Indiana-Kentucky border and I-275's Indiana-Kentucky border. It is also worth noting that I-94 westbound from Indiana to Illinois has many significant outliers and the same goes for I-65 southbound from Indiana to Kentucky, I-64 EB and southbound between Indiana and Kentucky, I-275 outer loop between Indiana and Ohio and between Indiana and Kentucky, I-90 EB from Illinois to Indiana, and I-90 westbound from Ohio to Indiana. Another key observation that can be observed from the box and whisker plot is that there is very minimal Indiana-Michigan border queuing as well as little border queuing on I-69 and I-70.

As mentioned, there can be many different causes for each border-queue. Five cases have been selected for a deeper analysis as to what some of these queues look like, where they are, when they are, and how severe they can be. The cases chosen are i, ii, iii, iv, and v corresponding with I-90 EB from Illinois into Indiana, I-94 WB into Illinois from Indiana, I-275 outer loop from Indiana into Kentucky, I-64 EB from Indiana into Kentucky, and I-90 WB from Ohio to Indiana, respectively.

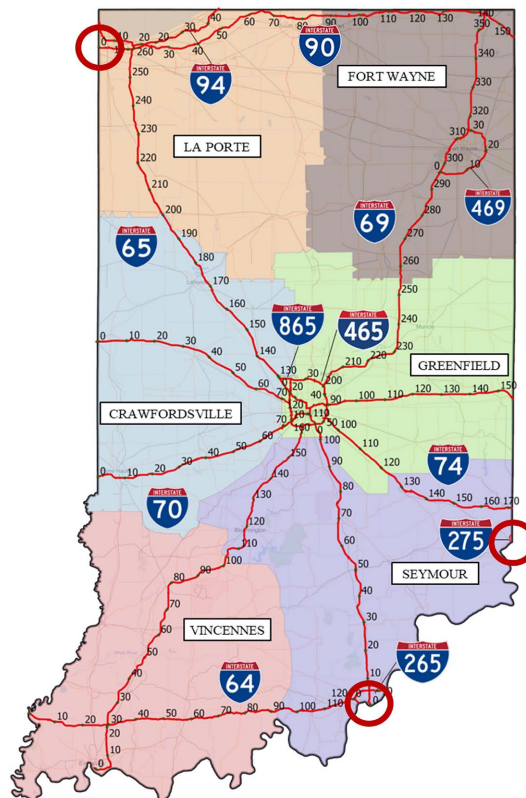


Figure 8. Indiana interstate map-critical borders.

Referencing **Figure 7**, the borders with the most significant presence of cross border queuing during the annual period from July 1st, 2024, to June 30th, 2025, were the I-94 Indiana-Illinois, I-64 Indiana-Kentucky, and I-275 Indiana-Kentucky borders with their locations marked on the Indiana map. In **Figure 8**, the top circle notes the I-94 Indiana-Illinois borders, the bottom circle notes the I-64 Indiana-Kentucky Borders, and the circle in between represents the I-275 Indiana-Kentucky Borders.

5. Discussion

5.1. Selected Queuing Examples on I-90, I-94, I-275, and I-64

The four cases selected are on four different interstates, I-90, I-94, I-275, and I-64 and correspond to callouts i, ii, iii, and iv in **Figure 7**, respectively. Their approximate geographic locations are shown in **Figure 8**. More details on the geographical location are shown in **Figure 9**. The first case, **Figure 9(a)**, is the border from the Chicago area of Illinois into Northwest Indiana and the second case, **Figure 9(b)**, is from Northwest Indiana to Illinois, in the Chicago area. The third case, **Figure 9(c)**, is the border from Southeast Indiana to Kentucky at Cincinnati and the interstate is only about 3 miles long in Indiana and enters Ohio. Lastly, the fourth case, **Figure 9(d)**, is a route that leaves Southeast Indiana and enters Kentucky and Louisville. Immediately, an important factor that is leading to congestion across the state borders is the fact that these interstates are located in densely populated urban areas. Naturally, more motorists on the interstate are correlating with increased congestion.

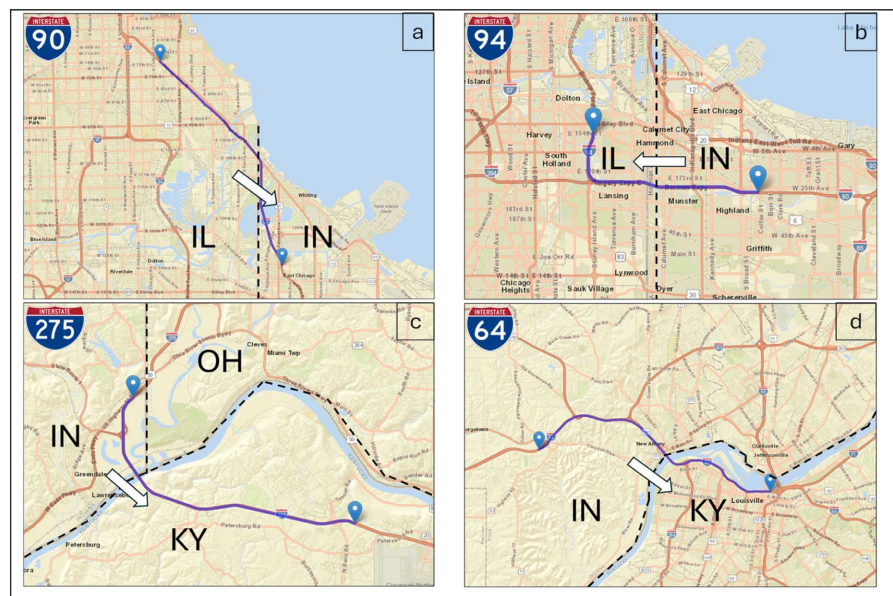


Figure 9. Indiana border queuing map visual.

Figure 10 shows two sample heatmaps. **Figure 10(a)** corresponds with Case i, I-90 EB from Illinois into Indiana and **Figure 10(b)** corresponds with Case ii, I-

94 WB from Indiana into Illinois. These two cases occurred on June 27th, 2025, and November 21st, 2024, respectively.

For **Figure 10(a)**, you can see the first signs of queuing in Indiana starting at approximately 11:30 EST and by 12:30 EST that queue has extended into Illinois. That queuing does not substantially clear until 18:30 EST. Also, one can observe queuing starting at the Indiana I-90 toll booth at 11:30 EST around MM 1. The queue from this toll booth backed up all the way over the Illinois-to-Indiana border where the queue reached over the border into Illinois as far back as MM 105.5 at 17:00 EST. After executing the query on the connected vehicle data on this cross-border queuing, the toll booth queuing accumulated to 2.8 hours of congestion across the border.

For **Figure 10(b)**, the first signs of queuing in Illinois start at approximately 10:30 EST and by 11:00 EST that queue has extended into Indiana. That queuing does not substantially clear until 13:00 EST. The queue can be seen re-emerging at around 15:00 EST and extend into Illinois by 15:30 EST. This section of queuing does not substantially clear until 20:00 EST. It is to be noted that the cross-border queuing from 11:00 to 13:00 EST does have speeds varying above and below the queuing query speed threshold of 45 miles per hour. Analysis on the CV data from this day showed congestion of 5.7 hours across the Indiana to Illinois border which was the highest queue for this border and direction in the annual period. This section of I-94 in Illinois route runs concurrently with I-80 from mile marker 74.5 to the Indiana-Illinois border and experiences high volume of traffic.

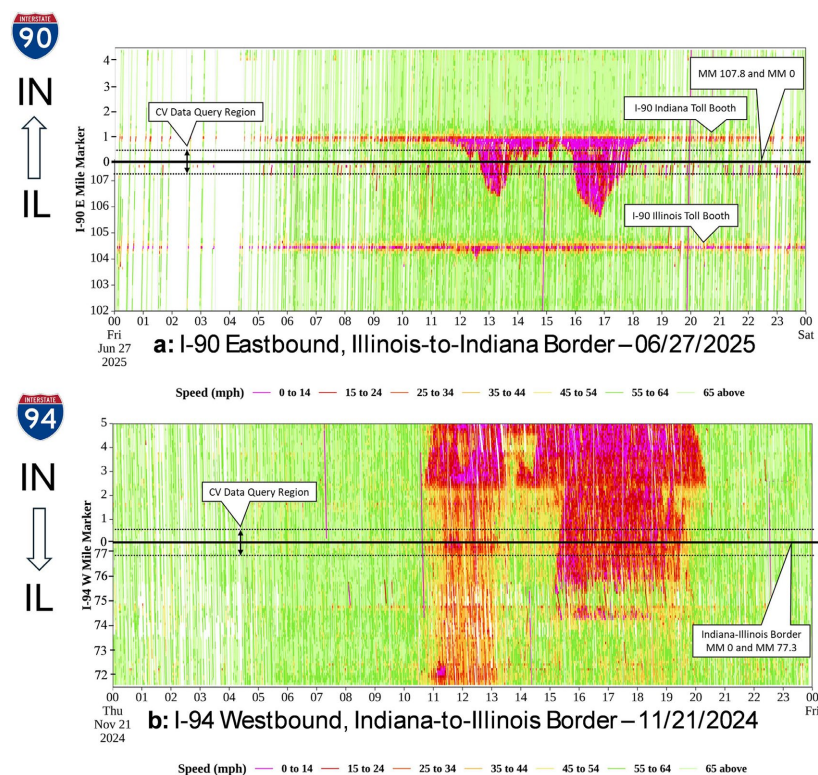


Figure 10. Indiana border queuing heatmaps-I-90 and I-94 cases.

Figure 11 shows two sample heatmaps. **Figure 11(a)** corresponds with Case iii, I-275 outer loop from Indiana into Kentucky and **Figure 11(b)** corresponds with Case iv, I-64 EB from Indiana into Kentucky. These two cases occurred on March 17th, 2025, and August 1st, 2024, respectively.

For **Figure 11(a)**, you can see the first signs of queuing in Kentucky starting at approximately 05:30 EST and by 06:30 EST that queue has extended into Indiana. That queuing does not substantially clear until 19:00 EST. It can be pointed out that the severity of the queues varies during this time range. The cross-border queuing can be seen to be particularly slow near the purple regions that occur from 07:00 to 08:30 EST, 11:00 to 12:00 EST, and 15:30 to 18:30 EST where queues started at about MM 13.2 and extend into Indiana as far back at MM 16, MM 16.5, and MM 16.5, respectively. The cross-border analysis section happens to overlap with the location of a bridge at the Indiana-Kentucky border on I-275, indicated in **Figure 11(a)**. A key characteristic to note about I-275 at the Indiana-Kentucky border is that the 14th mile is skipped for the mile markers. The approximately mile-long bridge starts at MM 13.2 at the Kentucky side and ends at about MM 15.2, indicating a mile-long gap across the border.

With the mentioned time frames of cross-border congestion, most speeds in the analysis region fluctuated above and below the threshold speed of 45 miles per hour. Once a query was executed over the connected vehicle data, it appeared that there were 3 hours of queuing over the Indiana-Kentucky border.

For **Figure 11(b)**, you can see the first signs of queuing in Kentucky starting at approximately 06:00 EST and by 07:30 EST, that queue has extended into Indiana. That queuing does not substantially clear until 09:30 EST. This initial queue can be seen extending as far back as MM 122 in Indiana. Queuing can be seen to briefly re-emerge at around 17:00 EST. This section of queuing does not substantially clear until 17:30 EST and does not extend much past the 0.5 MM in Indiana. Additionally, this cross-border mile-query section happens to partially overlap with the location of a bridge at the Indiana-Kentucky border on I-64, indicated in **Figure 11(b)**. Analysis on the CV data from this day showed congestion of 2.8 hours across the Kentucky to Indiana border.

5.2. Selected Travel Times for I-90, I-94, I-275, and I-64

After reviewing **Figure 10** and **Figure 11**, a good understanding of where these border queues are occurring is established and urban areas near state borders are hotspots for regular cross-border queuing congestion. However, getting a full understanding of the severity of these queues for motorists on the road can be difficult to interpret from just heatmaps. **Figure 12** presents motorist's travel times. This type of analysis characterizes the motorist's experience traveling through these selected segments of significant queuing.

In **Figure 12**, the travel times for cases i, ii, iii, and iv can be seen during their respective day time frames. Case i, ii, iii, and iv correspond to **Figure 12(a)**, **Figure 12(b)**, **Figure 12(c)**, and **Figure 12(d)** respectively. In **Figure 12(a)**, it took a mo-

torist 52 minutes to get through a 10-mile segment which included crossing the border queue. This motorist entered the segment just after 16:00 EST and traveled at an average speed of about 11.5 miles per hour on I-90.

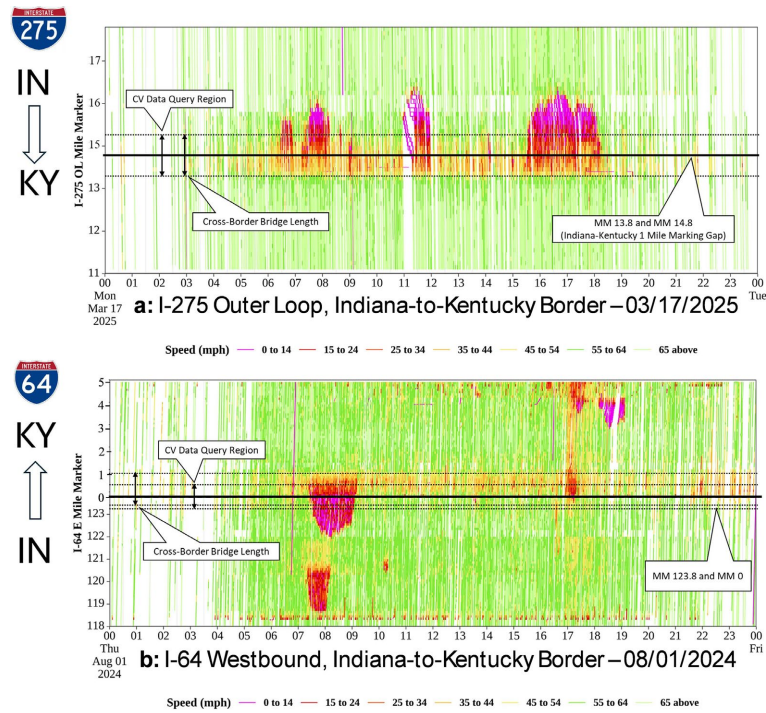


Figure 11. Indiana border queuing heatmaps-I-275 and I-64 cases.

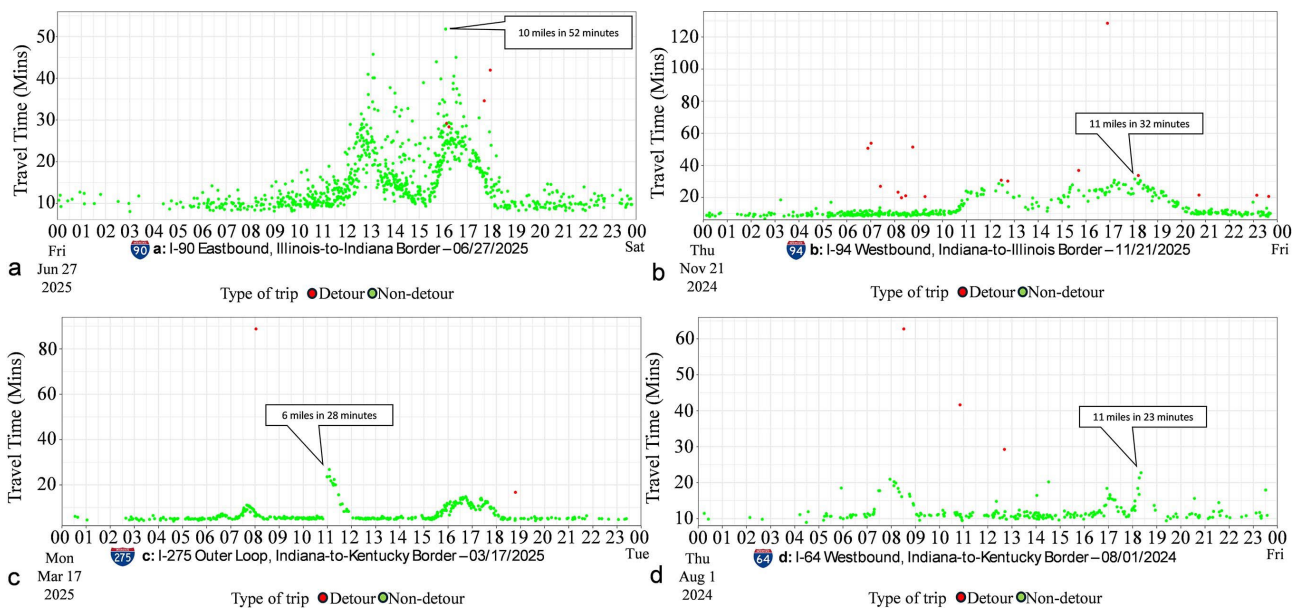


Figure 12. Indiana border queuing travel times.

For Figure 12(b), there was a motorist who entered an 11-mile segment including the cross-border queue section at about 18:00 EST. To get through the 11-mile

segment, it took the motorist 32 minutes which had the motorist traveling at an average speed of 20.6 miles per hour.

In **Figure 12(c)**, it took a motorist 28 minutes to get through a 6-mile segment which included crossing over the I-275 bridge border queue. This motorist entered the segment just after 11:00 EST and traveled at an average speed of about 12.9 miles per hour on I-90.

For **Figure 12(d)**, there was a motorist who entered a 11-mile segment including the cross-border queue section at about 18:30 EST. Getting through this border segment, it took the motorist about 23 minutes which meant the motorist was traveling at an average speed of 28.7 miles per hour, which was far better than the other three cases, but still is not a safe speed to be driving on any interstate.

5.3. Case Study with a Toll Plaza and Adjacent Workzone

Figure 13 depicts a unique border case with a couple of factors impacting queuing characteristics pointed out. Case v takes place on I-90 westbound from Ohio into Indiana.

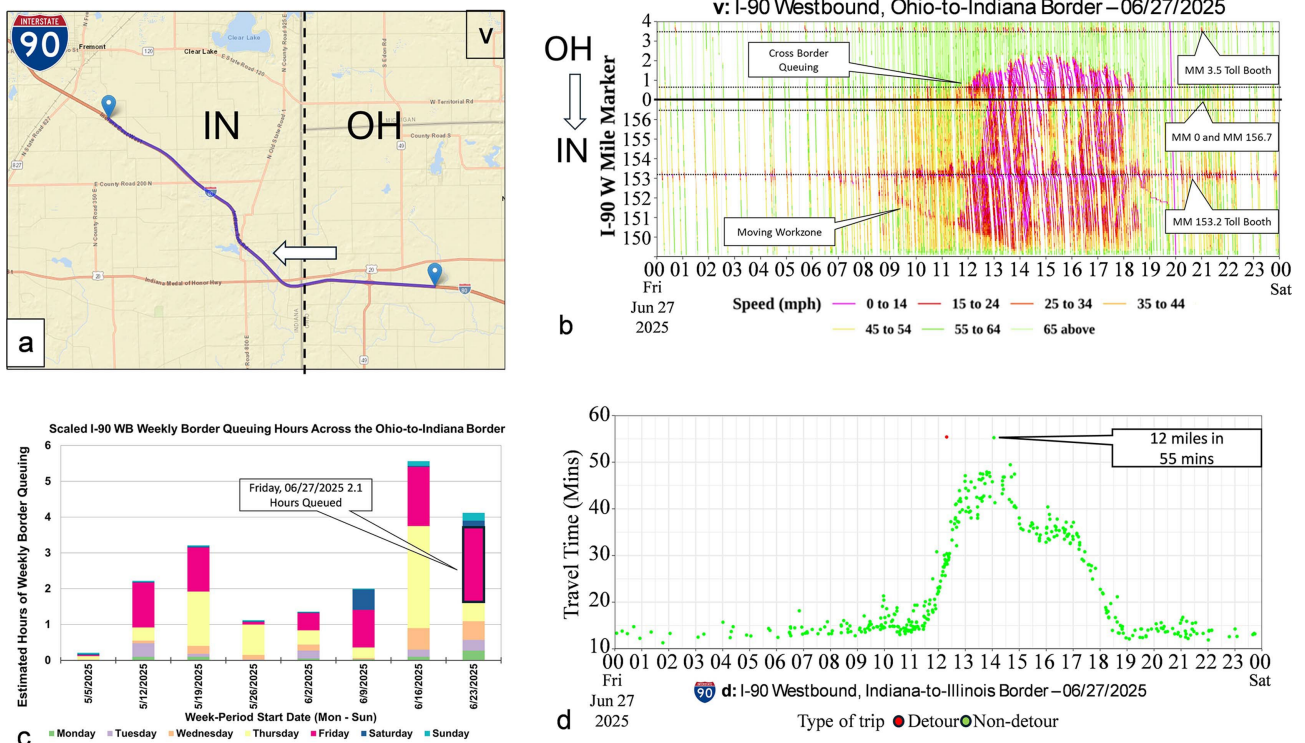


Figure 13. Indiana border queuing Case v.

As shown in **Figure 13(a)**, I-90 from Ohio into Indiana is examined over a 12-mile segment across the border going westbound. **Figure 13(b)** reflects the heatmap over the course of **Figure 13(a)**'s route on Friday, June 27th.

For **Figure 13(b)**, you can see the first signs of queuing in Indiana starting at approximately 11:30 EST and by 12:30 EST that queue has extended into Ohio.

That queuing does not substantially clear until 18:30 EST. This queue can be seen extending as far back as MM 2 in Ohio and the front-of-queue can be seen to start as far up as MM 149 in Indiana. As the congestion from the front of queue backs up to the Indiana-Kentucky border, execution of a query on the CV data reveals cross-border queuing of 2.1 hours. From 15:00 to 17:00 EST, it can be observed that the analysis region is only partially congested which can be a big contributor to a lower cross-border queue than anticipated.

The location of the I-90 toll plazas on this route are at MM 3.5 in Ohio and MM 153.2 in Indiana. These toll booths appear to have minor effects on queuing. However, there appears to be a moving work zone which can be seen moving from about mile marker 153 at the Indiana toll booth until about mile marker 149.5 from 07:00 to 14:00 EST, respectively.

In **Figure 13(c)**, the query shows 2.1 hours of queuing over the Ohio-to-Indiana border. Comparatively, this queue is very significant as this is the second biggest queue in the 8-week time frame. Additionally, **Figure 13(c)** reveals how Thursday and Friday have been common days for larger queues on I-90 at the Indiana-Ohio border, westbound.

Regardless of the hours queued, **Figure 13(d)** shows the travel times from the 12-mile segment over the Ohio-to-Indiana border. In one case, it took a motorist 55 mins to travel the segment at an average speed of 13.1 miles per hour and this motorist began their journey through this segment at about 14:00 EST.

This example documents the combined impact of a toll plaza and work zone congestion on the motorist journey over 12 miles that spans two states. These types of quantitative visualization tools are valuable tools for agencies to use to coordinate with stakeholders such as contractors and engineers planning future work.

5.4. Summary of Analysis and Data

A scalable process was developed that looked at interstate segment speeds within half a mile on each side of the border and tabulated the number of 1-minute aggregated intervals when 70% or more of the total 1-mile segment was experiencing an aggregated mean speed of less than 45 mph. These 1-mile border segments, consisting of ten 0.1-mile segments were used to produce this evaluation of cross-border queuing. This data was categorized by day and week, quantified in aggregated hours of queuing. Weekly summary graphs of this data were produced for 8 interstates, bidirectionally, for 13 total borders. A detailed example of the development of those weekly summaries was prepared for I-94 in **Figure 3** and **Figure 4** with detailed weekly heatmaps illustrating the aggregation concepts. **Figure 7** provides a summary box and whisker plot for all interstate crossings for the 26 interstate entrance to and exits from Indiana. To visualize the weekly/seasonal variation, **Figure 14** highlights the most significant Inbound and Outbound queuing to and from Indiana.

In **Figure 14(a)**, I-94 EB from Illinois to Indiana, it shows queues year-round.

This congestion is a result of a high volume of motorists on the interstate. However, certain timeframes of the year experience significant queuing elsewhere. From July 2024 to November 2025, westbound I-64 from Kentucky to Indiana has substantial queuing. Additionally, I-275 inner loop from Kentucky to Indiana has significant queuing from mid-December 2024 to the end of June 2025. I-90 EB from Illinois to Indiana appears to have some significant queues in July of 2024 and June of 2025 and I-90 westbound from Ohio to Indiana also had increasing queuing in May of 2025. Some major queue events can be identified in this figure as well, including I-94 westbound from Michigan to Indiana in the week of September 2, 2024, as well as I-275 outer loop from Ohio to Indiana during the weeks of December 16th, 2024, and January 13th, 2025.

In **Figure 14(b)**, the I-275 outer loop from Indiana to Kentucky has significant queuing, starting from mid-December 2024 to late June of 2025. The reason for this queuing is due to a lane restriction on the Carroll Lee Cropper Bridge [19]. The lane restriction is a result of preparation for construction on the bridge. Then for the beginning of the annual period, I-64 EB from Indiana to Kentucky has significant queuing from the beginning of July to the end of October. Similarly, this queuing is a result of lane closures at the Sherman Minton Bridge into Louisville [20].

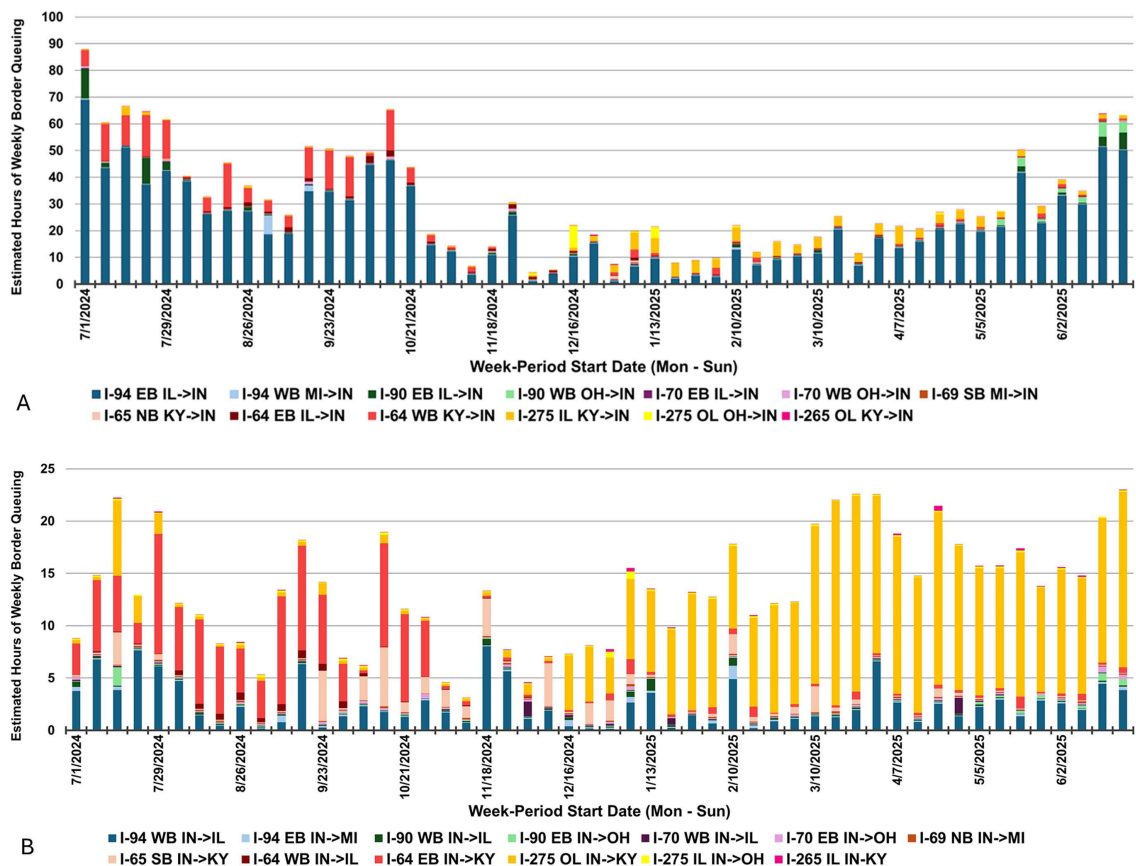


Figure 14. Hours of interstate queuing at Indiana borders (a) Inbound interstate locations (b) Outbound interstate locations.

6. Conclusions

The objective of this paper is to develop procedures to use connected vehicle data to monitor speeds in segments immediately adjacent to the border and identify time, duration, and severity of these inbound and outbound interstate locations. This paper introduces the use of connected vehicle data to quantitatively monitor queuing during the timeframe of July 1st, 2024, to June 30th, 2025.

- **Figure 3** provided a graphical illustration of queuing on one day at one location.
- Subsequently **Table 1** and **Figure 4** described how summary data could be derived and summarized over a week and subsequently an entire year **Figure 5** and **Figure 6**.
- Several case studies were presented that illustrated how high-level trends can be identified with the ability to drill down for additional detail.
- Finally, annual inbound and outbound trends were characterized in **Figure 14**.

In conclusion, these data analysis and visualization techniques provide a mechanism for a state to understand the impact that congestion in other states have on their freeways, as well as the impact their congestion has beyond their borders. These types of quantitative information help facilitate constructive regional dialog to help identify future capital projects that can improve regional mobility.

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Authors' Contributions

The authors confirm contribution to the paper as follows: study conception and design: T.M.D., R.S.S., J.D. and D.M.B.; data collection: T.M.D., R.S.S. and J.D.; analysis and interpretation of results: T.M.D. and D.M.B.; draft manuscript preparation: T.M.D. and D.M.B.; All authors reviewed the results and approved the final version of the manuscript. This study is based upon work supported by the Joint Transportation Research Program administered by the Indiana Department of Transportation and Purdue University and by the Center for Connected and Automated Transportation administered by the University of Michigan.

Conflicts of Interest

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

References

- [1] Mekker, M.M., Remias, S.M., McNamara, M.L. and Bullock, D.M. (2020) Characterizing Interstate Crash Rates Based on Traffic Congestion Using Probe Vehicle Data. Purdue University.
- [2] Brent, D. and Beland, L. (2020) Traffic Congestion, Transportation Policies, and the Performance of First Responders. *Journal of Environmental Economics and Management*, **103**, Article ID: 102339. <https://doi.org/10.1016/j.jeem.2020.102339>
- [3] Jalilifar, E., Li, X., Martin, M. and Huang, X. (2024) Exploring the Potential of Market-Available Connected Vehicle Data in Border Crossing Time Estimation. *Transactions in Urban Data, Science, and Technology*, **3**, 31-45. <https://doi.org/10.1177/27541231241226730>
- [4] Medeiros, E. (2019) Cross-Border Transports and Cross-Border Mobility in EU Border Regions. *Case Studies on Transport Policy*, **7**, 1-12. <https://doi.org/10.1016/j.cstp.2018.11.001>
- [5] Chilla, T. and Heugel, A. (2019) Cross-Border Commuting Dynamics: Patterns and Driving Forces in the Alpine Macro-Region. *Journal of Borderlands Studies*, **37**, 17-35. <https://doi.org/10.1080/08865655.2019.1700822>
- [6] Decoville, A., Durand, F., Sohn, C. and Walther, O. (2013) Comparing Cross-Border Metropolitan Integration in Europe: Towards a Functional Typology. *Journal of Borderlands Studies*, **28**, 221-237. <https://doi.org/10.1080/08865655.2013.854654>
- [7] Rahman, M.M., Najaf, P., Fields, M.G. and Thill, J. (2021) Traffic Congestion and Its Urban Scale Factors: Empirical Evidence from American Urban Areas. *International Journal of Sustainable Transportation*, **16**, 406-421. <https://doi.org/10.1080/15568318.2021.1885085>
- [8] Knaap, E. and Rey, S. (2024) Measuring Two Decades of Urban Spatial Structure: The Evolution of Agglomeration Economies in American Metros. *Computers, Environment and Urban Systems*, **110**, Article ID: 102116. <https://doi.org/10.1016/j.compenvurbsys.2024.102116>
- [9] Fang, S. and Ma, J. (2021) Influence Range and Traffic Risk Analysis of Moving Work Zones on Urban Roads. *Sustainability*, **13**, Article No. 4196. <https://doi.org/10.3390/su13084196>
- [10] Bhutani, R., Ram, S. and Ravinder, K. (2016) Impact of Metro Rail Construction Work Zone on Traffic Environment. *Transportation Research Procedia*, **17**, 586-595. <https://doi.org/10.1016/j.trpro.2016.11.113>
- [11] Chung, Y. (2011) Assessment of Non-Recurrent Traffic Congestion Caused by Freeway Work Zones and Its Statistical Analysis with Unobserved Heterogeneity. *Transport Policy*, **18**, 587-594. <https://doi.org/10.1016/j.tranpol.2011.02.003>
- [12] Splawińska, M. (2017) Factors Determining Seasonal Variations in Traffic Volumes. *Archives of Civil Engineering*, **63**, 35-50. <https://doi.org/10.1515/ace-2017-0039>
- [13] Bi, H., Ye, Z. and Zhu, H. (2022) Data-Driven Analysis of Weather Impacts on Urban Traffic Conditions at the City Level. *Urban Climate*, **41**, Article ID: 101065. <https://doi.org/10.1016/j.uclim.2021.101065>
- [14] Sakhare, R.S., Hunter, M., Mukai, J., Li, H. and Bullock, D.M. (2022) Truck and Passenger Car Connected Vehicle Penetration on Indiana Roadways. *Journal of Transportation Technologies*, **12**, 578-599. <https://doi.org/10.4236/jtts.2022.124034>
- [15] Remias, S., Brennan, T., Grimmer, G., Cox, E., Horton, D. and Bullock, D. (2011) Indiana Interstate Mobility Report-Full Version. Purdue University.
- [16] Sakhare, R.S., Desai, J., Mathew, J.K., McGregor, J., Kachler, M. and Bullock, D.M.

-
- (2024) Measuring and Visualizing Freeway Traffic Conditions: Using Connected Vehicle Data. Purdue University.
- [17] Brennan, T.M., Remias, S.M., Grimmer, G.M., Horton, D.K., Cox, E.D. and Bullock, D.M. (2013) Probe Vehicle-Based Statewide Mobility Performance Measures for Decision Makers. *Transportation Research Record: Journal of the Transportation Research Board*, **2338**, 78-90. <https://doi.org/10.3141/2338-09>
- [18] Fitzpatrick, K., Shamburger, B. and Fambro, D. (1996) Design Speed, Operating Speed, and Posted Speed Survey. *Transportation Research Record: Journal of the Transportation Research Board*, **1523**, 55-60. <https://doi.org/10.1177/0361198196152300107>
- [19] WCPO 9 Cincinnati, Rowan A. I-275 Carroll Cropper Bridge Lane Closures: Here's Why There's Not More Construction Activity Happening. <https://www.wcpo.com/traffic/i-275-carroll-cropper-bridge-lane-closures-heres-why-theres-not-more-construction-activity-happening>
- [20] INDOT. Sherman Minton Corridor Project. <https://www.in.gov/indot/doing-business-with-indot/request-for-qualifications/sherman-minton-corridor-project/>