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Using Connected Truck Trajectory Data to Compare Speeds in States with and without Differential Truck Speeds

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Abstract

Historically, researchers and practitioners have utilized spot speeds and microscopic simulation methodologies to evaluate the operational impact of differential or uniform speed limits for trucks and passenger vehicles. This paper presents a methodology that uses connected truck data to develop a statistical characterization of both passenger car and truck speeds. These techniques were applied to three adjacent states, Illinois, Indiana and Ohio. Illinois and Ohio have 70 mph speed limits for both trucks and cars. Indiana has a differential speed limit for heavy trucks (65 mph) and passenger cars (70 mph). The statistical distribution of truck speeds was then compared among Illinois, Indiana and Ohio. These speeds were derived from over 8 million connected truck records traveling along Interstate 70 in Illinois, Indiana and Ohio during a one-week period from May 8-14, 2022. Statistical test results over selected 20-mile sections in each state showed that median truck speeds in Indiana with its differential speed limit of 65 mph were only 1 - 2 mph lesser than the neighboring states of Illinois and Ohio who observe a uniform speed limit of 70 mph for all traffic.

Keywords

Connected Vehicle Data, Trucks, Differential Speed Limits, Interstates

1. Introduction

The National Maximum Speed Law, passed by the United States federal government in 1974 resulted in a maximum allowed vehicle speed limit of 55 miles per hour (mph) on all interstate roadways in the United States. Subsequently, the Surface Transportation and Uniform Relocation Assistance Act of 1987 and the

National Highway Designation Act of 1995 essentially repealed all federal controls on speed limits allowing states to set their own individual speed limits [1]. This eventually led to a number of states increasing regulatory speed limits on their roadways with a few among them choosing to implement differential speed limits (DSL) for trucks and passenger vehicles for rural interstate sections. While a majority of research has focused on the safety impacts of DSLs on freeway traffic, this study aims to provide quantitative data on the impact a DSL has on instantaneous and space mean speeds for trucks for the state of Indiana (an example of DSL signage is shown by callout i on **Figure 1**) compared to neighboring states implementing a uniform speed limit (USL).

2. Literature Review

Microscopic simulation methodologies, crash estimation models and multi-year studies collecting crash incident data have long been utilized to research the safety implications of a differential speed limit for trucks and passenger vehicles on roadways [2] [3]. Multiple studies focusing on existing and planned transportation infrastructure have also explored the possibility of optimizing curve radius, roundabout clearance and roadway geometric design in general, to reduce truck rollover propensity and improve safety [4] [5] [6]. A comprehensive 9-year research effort looking at the six US states of Arizona, North Carolina, Washington, Arkansas, Idaho and Virginia found no consistent safety effect of implementing DSLs or switching from USLs to DSLs [7]. A 17-state study that also focused on DSLs on rural interstate highways looked at crash, traffic volumes and speed monitoring datasets and found no consistent safety effects of implementing a DSL compared to a USL [8].

A multi-national study on the effects of DSLs performed by the Federal Highway Administration (FHWA) revealed that DSLs may result in unwanted high-speed differentials on freeways posing potential safety concerns for the traveling public. DSLs often lead to increased lane changing behavior leading to

Figure 1. Example of DSL Signage in Indiana that shows a speed limit of 65 mph for trucks and 70 mph for all other vehicles.

disrupted traffic flow [9]. A three-state study observing vehicle speeds in Indiana, Michigan and Ohio using spot speed comparisons at 157 different sites on rural and urban freeways found the highest variance in travel speeds for vehicles were locations with DSLs [10]. A 1992 study of speed and crash incident data on Interstates 64, 77 and 81 found that speed variances for all vehicles were significantly higher in Virginia with a DSL compared to the same routes operating under a USL in West Virginia [11]. A recent study evaluating the potential impacts of changing speed limits on Indiana's freeways using the National Performance Management Research Data Set (NPMRDS) of average travel times aggregated by nearly 2.5 mile long freeway segments observed that replacing the DSL for rural interstates with a USL of 70 mph may be beneficial for both mobility and safety, while increasing speed limits for urban interstates may aid mobility while detrimentally impacting safety [12]. Although these evaluations yield extremely valuable and impactful results, they are highly time consuming and labor intensive and may not provide trajectory level detail due to inherent aggregation.

A variable speed limit study for a work zone in Indiana evaluated individual driver responses for both cars and trucks using vehicle matching to observe the impacts of Variable Speed Limit (VSL) signage on driver behavior and speed limit compliance using speed measurement lasers to record spot speeds [13]. Bluetooth probe data acquisition stations providing an 11% sampling rate were leveraged by a study evaluating the spatial and temporal impacts of enforcement activity on work zone speed limit compliance [14]. These methodologies and the resulting analysis presented actionable insights for agencies in trialing various speed limit compliance techniques. However, they rely heavily on fixed infrastructure and may pose significant costs to stakeholders for continuous monitoring and analysis.

Connected vehicle data on the other hand has shown great promise in recent years in providing stakeholders with a scalable option to monitor traffic operations without using sensor-based infrastructure [15]. Agencies in Indiana and Pennsylvania among others have already leveraged connected vehicle data for passenger cars for evaluating the effectiveness of automated work zone enforcement, speed feedback displays and speed limit signs in work zones [16] [17]. A natural next step to these already well-established methodologies and analyses is using connected truck data for researching speed differential and speed compliance.

Spatially and temporally limited truck Automated Vehicle Locator System (AVL) and Global Positioning System (GPS) data at the fleet level has so far been applied to a variety of research objectives including freight modeling, forecasting, performance analysis, planning and truck stop parking utilization among others [18] [19] [20]. However, minimal research exists in using large scale connected truck data to effectively evaluate DSLs and USLs and thus provide quantitative evidence informing regulatory speed limit policy towards improving freeway safety and mobility.

3. Objectives and Scope

This study presents techniques to use emerging connected truck data to provide a scalable methodology that can be used to compare the statistical distribution of truck and passenger car speeds on Interstate 70 (I-70) corridor through the states of Illinois, Indiana, Ohio, West Virginia and Pennsylvania. These techniques are much more scalable that past techniques that have relied on field data collection. They are also much more robust than segment-based speed data sets.

4. Study Location

An overall map of the I-70 corridor passing through the states of Illinois, Indiana, Ohio, West Virginia and Pennsylvania is shown in **Figure 2**. The nearly 726-mile corridor runs for at least 150 miles in each state except West Virginia (14.1 miles) and was split into 14,525 segments in total for both directions of travel, each 0.1 mile in length to linearly reference the truck speed records. This corridor has also been highlighted by the USDOT and FHWA for conducting a feasibility study on dedicated truck lanes as one of their Corridor of the Future Program projects [21] [22]. The USDOT has additionally awarded a group of stakeholders including the Indiana Department of Transportation (INDOT) $4.4 million in 2020 towards researching truck automation solutions on the I-70 corridor spanning from Indianapolis, Indiana to Columbus, Ohio [23]. This choice of study location lines up well with recent federal and state-level investments in prioritizing freight mobility on I-70.

5. Connected Truck Data

Connected truck data available at 60-second frequency and 3-meter spatial accuracy was utilized for this study. Spatial polygons covering the entire analysis corridor were used to join and reduce the truck data down to records on I-70.

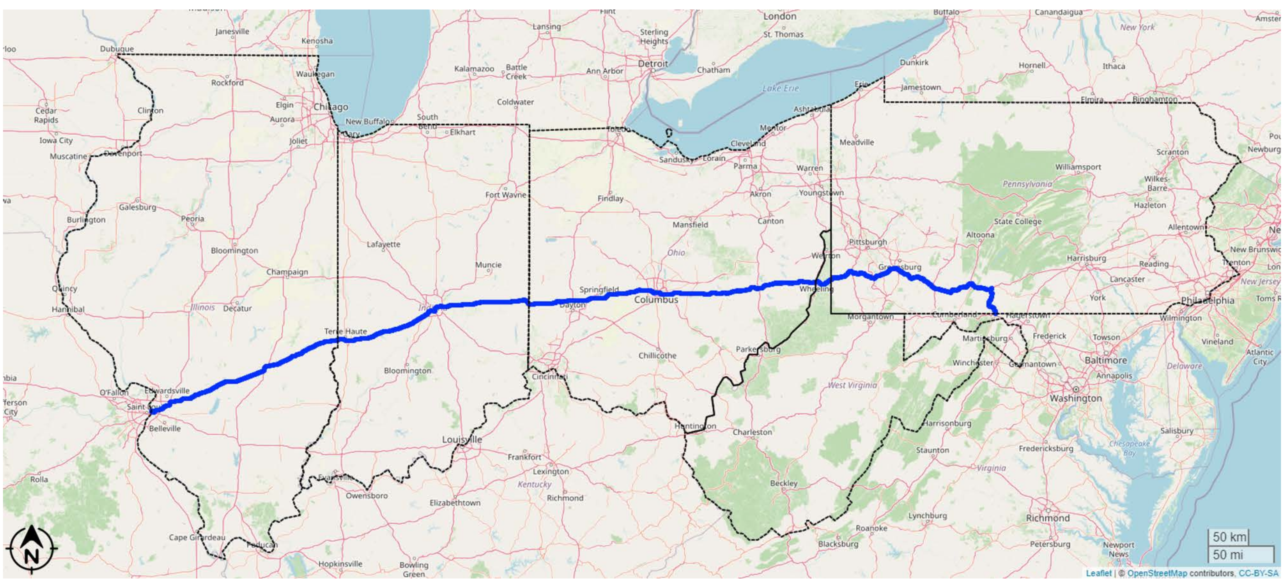


Figure 2. Overview map of I-70 (highlighted in blue) passing through Illinois, Indiana, Ohio, West Virginia and Pennsylvania.

The study focused on a one-week period from May 8-14, 2022. Approximately 10 million records were available for this period for trucks using the I-70 corridor. Each truck waypoint had a geolocation, timestamp, heading, speed and anonymized device identifier. In order to pinpoint truck speeds along the route, each truck waypoint was linearly referenced to a 0.1 mile segment on I-70 in the respective direction of travel using methodologies previously leveraged in existing literature for linearly referencing connected vehicle data for passenger cars [16].

6. Truck Speeds on I-70

Figure 3 shows a cumulative frequency distribution of all truck speed records captured on I-70 colorized by the state they were recorded in. Callout i points to a vertical dashed line at 65 mph representing the DSL for rural interstates for trucks in Indiana [24], while callout ii correspondingly points to the USL in the other states for rural interstates of 70 mph. The visualization is capped at 100 mph to remove extreme outlier speed records. Approximately 3% - 5% of records are seen to have recorded zero speeds shown by callout iii possibly pointing to trucks stopping by the side of the interstate on the shoulder for rest, unscheduled maintenance, or stopping in traffic due to congestion resulting from planned construction activity or unplanned stoppages caused by crash incidents. Indiana observes approximately 55% of records below the 65-mph limit. Although IN is the only state having DSL, the overall truck speeds between all

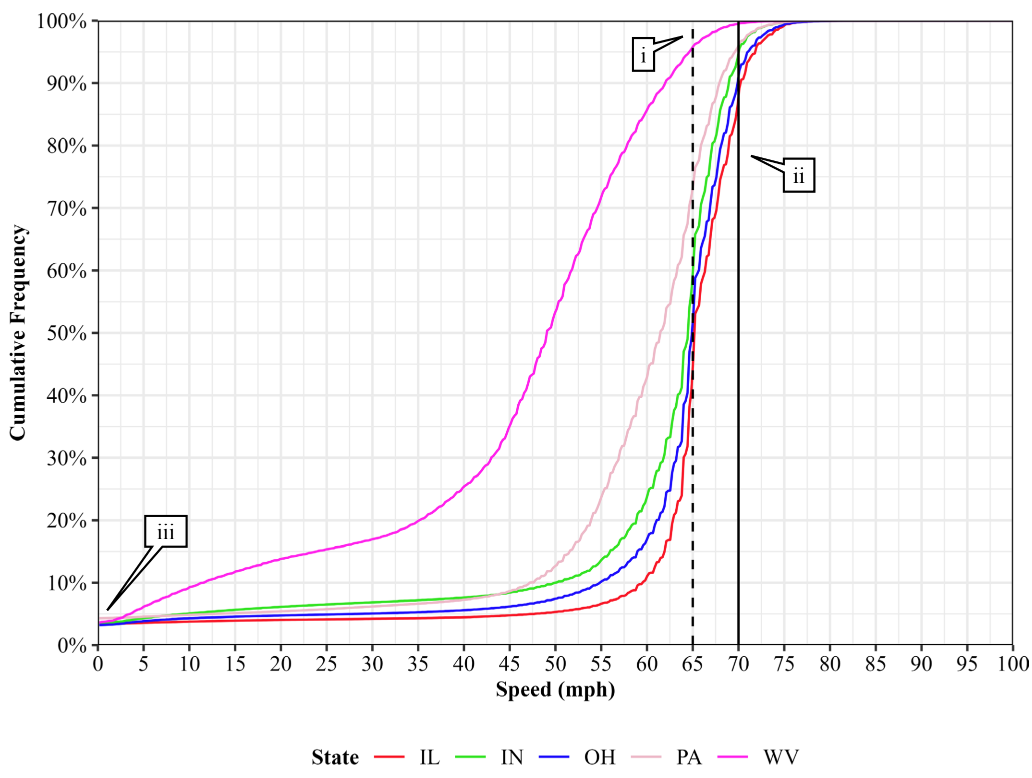


Figure 3. Cumulative frequency distribution of truck speeds on I-70 by US State (capped at 100 mph).

the states look similar, except for PA and WV possibly due to the terrain and grade changes. Moreover, the posted speed limit in a state may vary significantly between rural and urban sections of interstate and thus requires a more in-depth look.

Figure 4 below shows a more detailed spatial visualization of truck speeds aggregated for every mile, for both directions of travel, along I-70 across the five-state region. Callouts i through vi point to urban locations along the corridor, namely St. Louis, Indianapolis, Columbus, Zanesville, Wheeling and New Stanton, witnessing significant drops in truck speeds. More than 95% of speeds appear to have dropped below 65 mph in these locations.

For visibility on truck speed differences by the direction of travel (eastbound or westbound), an interquartile range (IQR) plot of truck speeds on I-70 aggregated every 10 miles by state is depicted by Figure 5(a) and Figure 5(b) for the eastbound and westbound directions of travel respectively, with rural interstate speed limits for trucks shown by horizontal red dashed lines. Significant speed drops are witnessed near urban areas in each state, similar to those pointed to by callouts in Figure 4, which again point to reduced interstate speed limits in urban sections. In order to have a consistent section for comparing truck speeds across states, 20-mile sections in the four states were chosen as pointed to by callouts i (MM 20 - 40 in Illinois), ii (MM 110 - 130 in Indiana), iii (MM 10 - 30 in Ohio) and iv (MM 110 - 130 in Pennsylvania). West Virginia was excluded from the analysis owing to a short corridor length. These sections were chosen as they were observed to have consistent median speeds outside of urban areas allowing for better comparison.

7. Instantaneous and Space Mean Truck Speeds on Chosen Sections

The state-to-state comparison of truck speeds is split into two broad subsections:

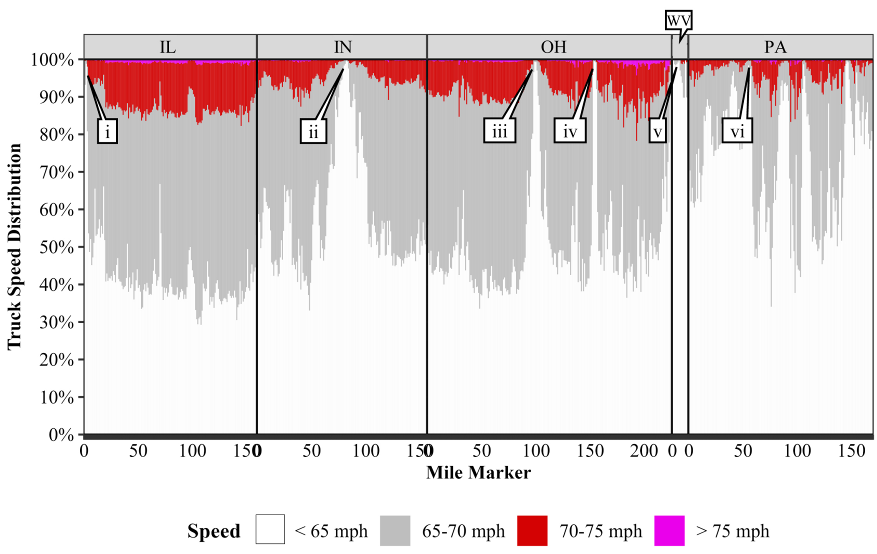
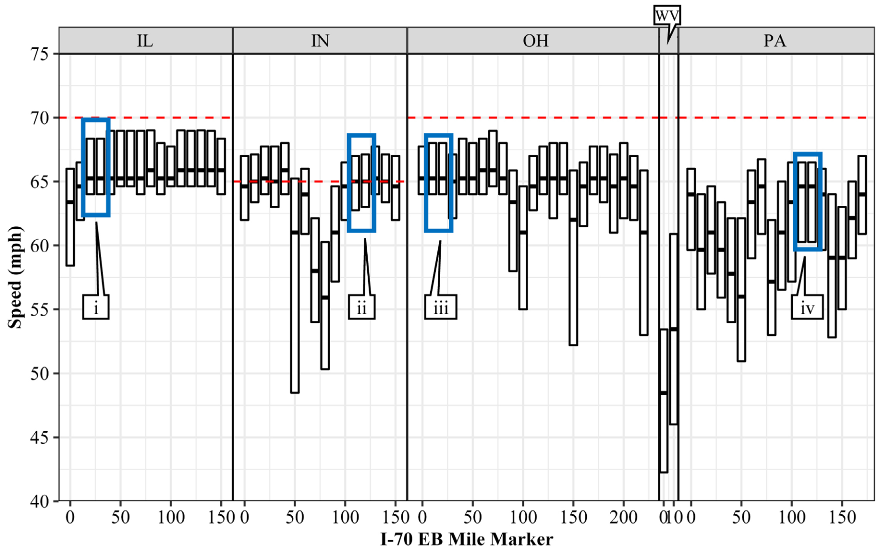
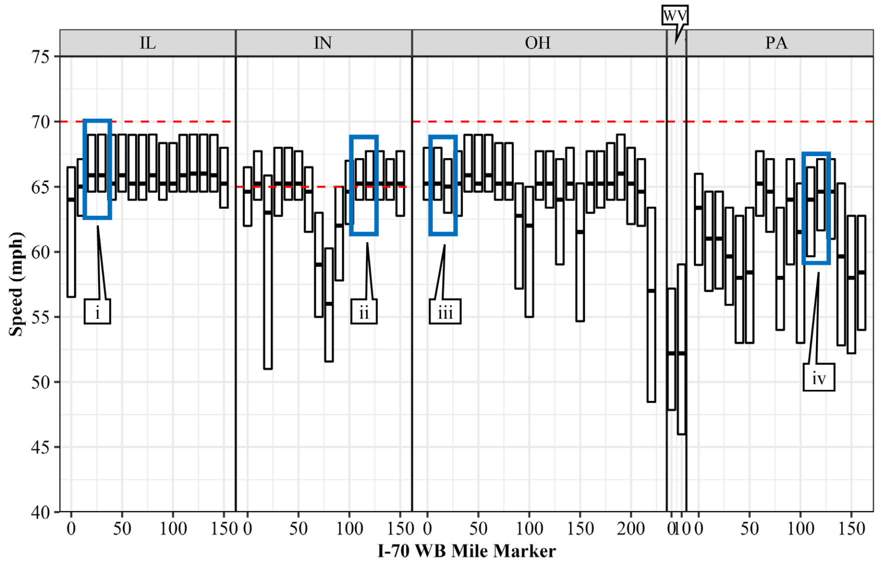


Figure 4. Spatial representation of truck speeds within 25 - 100 mph on I-70 by US state.



(a)



(b)

Figure 5. IQR speed plots of truck speeds within 25 - 100 mph on I-70 categorized into 10-mile segments. (a) I-70 Eastbound (EB); (b) I-70 Westbound (WB).

instantaneous truck speeds, considering all speed records observed in the chosen sections; and truck space mean speeds, considering the distance and travel time taken by every single truck to traverse a chosen section to capture a more holistic view of truck travel. In each case, speeds were limited to be in the range of 25 - 100 mph to filter out high outlier speeds as well as low speeds that may have been caused to congestion or crash incidents leading to saturated interstate traffic.

7.1. Instantaneous Truck Speeds

Instantaneous truck speeds recorded in each of the four analysis sections were plotted as a cumulative frequency distribution colorized by state as shown in Figure 6. For the westbound direction of travel, speeds in Indiana show high agreement with speeds in Ohio. For the eastbound direction of travel, speeds in Indiana show a slight left-shift pointing to a higher percentage of trucks traveling at reduced speeds due to an instance of non-recurring congestion observed in the chosen section on May 14, 2022.

Table 1 and Table 2 below represent summary statistics for instantaneous truck speeds observed during the one-week analysis period in the chosen 20-mile sections of I-70 for Illinois, Indiana, Ohio and Pennsylvania. Median speeds in the eastbound direction for Illinois, Indiana and Ohio are within 0.2 mph of each other, and those in the westbound direction are only separated by

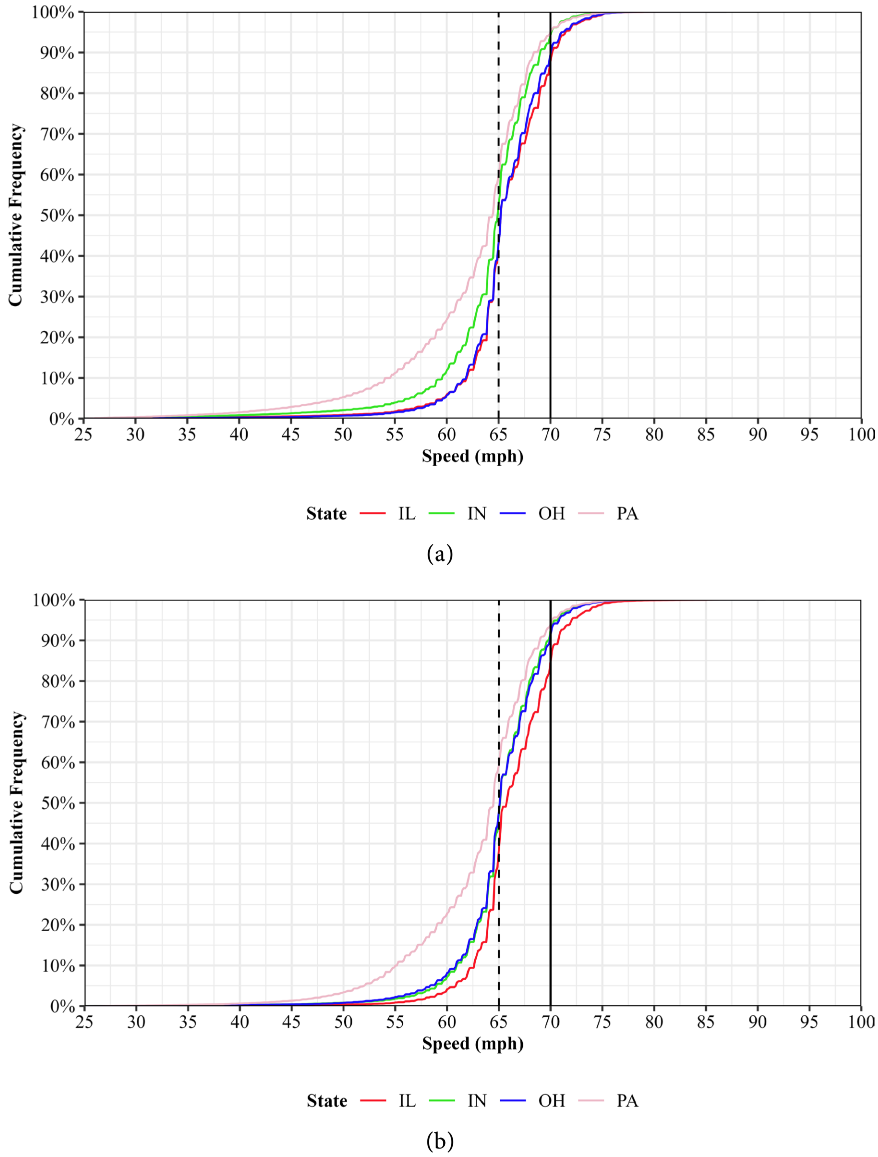


Figure 6. Cumulative frequency distribution of instantaneous truck speeds within 25 - 100 mph on I-70 for chosen 20-mile analysis sections by US State. (a) I-70 Eastbound; (b) I-70 Westbound.

Table 1. Instantaneous truck speed statistics for 20-mile analysis sections of I-70 EB by US state.

US State	Analysis Section	Posted Speed Limit (mph)	Number of Trips	EB Percentile Speeds (mph)			
				25th	50th	75th	85th
IL	MM 20 - 40	70	4700	64.0	65.2	68.4	70.0
IN	MM 110 - 130	65	7490	62.8	65.0	67.0	68.0
OH	MM 10 - 30	70	7978	64.0	65.2	68.0	69.6
PA	MM 110 - 130	70/55 (tunnels)	6326	60.3	64.6	66.5	67.7

Table 2. Instantaneous truck speed statistics for 20-mile analysis sections of I-70 WB by US state.

US State	Analysis Section	Posted Speed Limit (mph)	Number of Trips	WB Percentile Speeds (mph)			
				25th	50th	75th	85th
IL	MM 20 - 40	70	4322	64.6	65.9	69.0	70.0
IN	MM 110 - 130	65	7098	64.0	65.2	67.7	69.0
OH	MM 10 - 30	70	7818	64.0	65.2	67.7	69.0
PA	MM 110 - 130	70/55 (tunnels)	6726	60.9	64.6	67.0	68.0

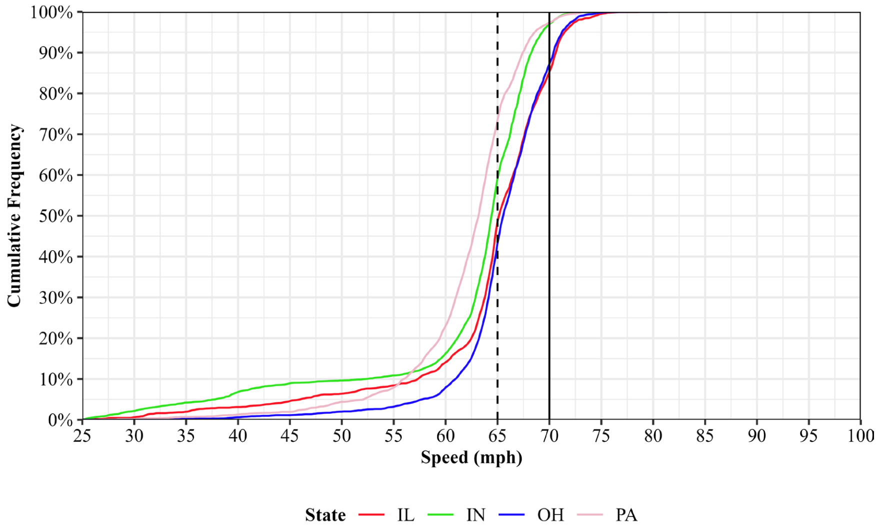
0.7 mph. This clearly points to a DSL in Indiana having minimal impact on instantaneous truck speeds compared to the USLs in neighboring Illinois and Ohio.

7.2. Truck Space Mean Speeds

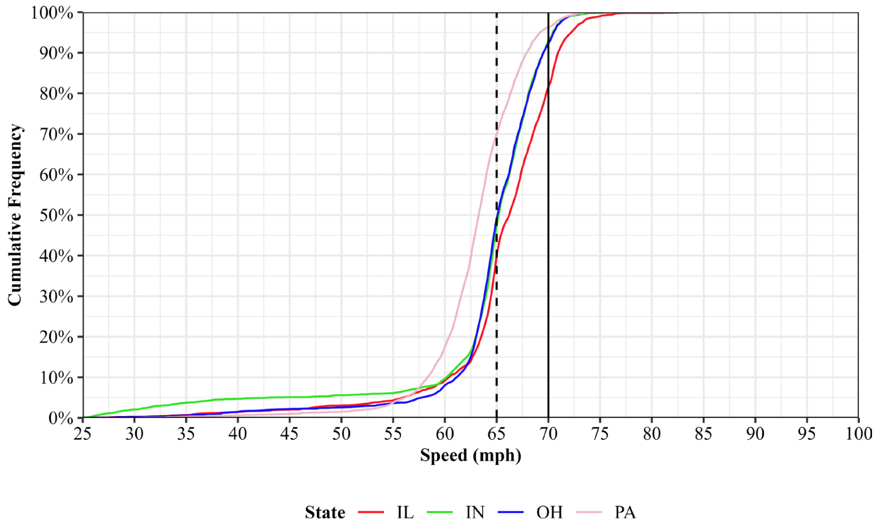
Truck space mean speeds were computed for each of the four analysis sections listed earlier, by recording the distance traveled and the travel times for each truck traversing the section. Space mean speeds in Figure 7 show similar trends as the instantaneous truck speeds from Figure 6.

Table 3 and Table 4 below similarly show summary statistics for truck space mean speeds in the eastbound and westbound directions of travel respectively. The 20-mile section in Ohio from MM 10 - 30 observed the highest number of truck trips in either direction of travel. Median space mean speeds for Indiana are within 1.1 to 1 mph of those in Illinois and Ohio for the EB and WB directions of travel respectively again pointing to only incremental differences in speeds in Indiana even with a DSL policy in effect.

A significant difference in number of trips is seen between instantaneous speeds (Table 1 and Table 2) and space mean speeds (Table 3 and Table 4). This difference stems from the methodology requiring trucks to have traveled at least 18.75 miles of the analysis section for their travel time to be considered in the computation of space mean speeds. This 18.75-mile threshold was chosen to allow for the truck data reporting threshold that may stretch for as long as 60 seconds potentially leading to more than a mile in missing recorded distance



(a)



(b)

Figure 7. Cumulative frequency distribution of truck space mean speeds within 25 - 100 mph on I-70 for chosen 20-mile analysis sections by US state. (a) I-70 Eastbound; (b) I-70 Westbound.

Table 3. Truck space mean speed statistics for 20-mile analysis sections of I-70 EB by US state.

US State	Analysis Section	Posted Speed Limit (mph)	Number of Trips	EB Percentile Speeds (mph)			
				25th	50th	75th	85th
IL	MM 20 - 40	70	1727	63.3	65.2	68.2	70.0
IN	MM 110 - 130	65	3080	62.4	64.5	66.7	67.7
OH	MM 10 - 30	70	3288	63.8	65.6	68.3	69.7
PA	MM 110 - 130	70/55 (tunnels)	2272	60.4	63.3	65.2	66.7

Table 4. Truck space mean speed statistics for 20-mile analysis sections of I-70 WB by US state.

US State	Analysis Section	Posted Speed Limit (mph)	Number of Trips	WB Percentile Speeds (mph)			
				25th	50th	75th	85th
IL	MM 20 - 40	70	1748	64.2	66.3	69.3	70.5
IN	MM 110 - 130	65	2932	63.6	65.3	67.7	68.8
OH	MM 10 - 30	70	3144	63.5	65.2	67.7	68.8
PA	MM 110 - 130	70/55 (tunnels)	2593	61.1	63.3	65.6	67.1

(1.25 miles at a speed of 75 mph). This also allowed to discard trips that exited in between without travelling the entire length of the analysis section. Instantaneous speeds however record every single record inside the analysis section irrespective of whether a truck traveled the entire 20-mile section or only a sub-section of it.

8. Statistical Tests Comparing Median Speeds

Unpaired non-parametric Wilcoxon rank sum tests [25] were conducted for comparing medians of instantaneous and truck space mean speeds in Indiana against those from Illinois, Ohio and Pennsylvania. The Wilcoxon rank sum test was performed to determine if the difference in medians of truck speeds between states was greater than a pre-defined threshold. This pre-defined threshold starting at 0 mph was increased in steps of 1 mph until statistical significance was observed. The analysis was stopped at the pre-defined speed that showed statistical significance, pointing to a rejection of the null hypothesis in favor of the alternative hypothesis that difference in median speeds is observed to be below this pre-defined speed threshold. Results from these tests are covered in the following subsections individually for instantaneous truck speeds and truck space mean speeds.

8.1. Instantaneous Truck Speeds

The statistical test for instantaneous truck speeds was conducted to determine whether the median instantaneous truck speed for the first state ($s1$) was greater than the median instantaneous truck speed for the second state ($s2$) by a pre-defined threshold (I_T). This pre-defined threshold, beginning at 0 mph, was raised in 1 mph increments until statistical significance was achieved rejecting the null hypothesis. Results of the tests in **Table 5** show that median instantaneous truck speeds for Illinois and Ohio are both only within 1 mph greater than those for Indiana. Median instantaneous truck speeds for Indiana on the other hand are only within 2 mph greater than those for Pennsylvania, possibly resulting from sections of the roadway in Pennsylvania passing through the Allegheny Tunnel thus lowering the traveling speed due to regulatory limits of 55 mph.

Table 5. Unpaired two-sample Wilcoxon tests comparing instantaneous truck speeds.

Comparison US States		Speed Difference Threshold (I_T)	Sample Size		Median Instantaneous Speed (mph)		Standard Deviation (mph)		P-value	Statistically Significant
State 1 (S1)	State 2 (S2)		S1	S2	S1	S2	S1	S2		
IL	IN	1	225,568	389,208	65.2	65.0	4.1	4.6	<0.001	Yes
OH	IN	1	420,378	389,208	65.2	65.0	4.1	4.6	<0.001	Yes
IN	PA	2	389,208	333,578	65.0	64.6	4.6	6.3	<0.001	Yes

Table 6. Unpaired two-sample Wilcoxon tests comparing truck space mean speeds.

Comparison US States		Space Mean Speed Difference Threshold (S_T)	Sample Size		Median Space Mean Speed (mph)		Standard Deviation (mph)		P-value	Statistically Significant
State 1 (S1)	State 2 (S2)		S1	S2	S1	S2	S1	S2		
IL	IN	2	3475	6012	65.6	64.9	7.1	8.7	<0.001	Yes
OH	IN	1	6432	6012	65.3	64.9	5.2	8.7	<0.001	Yes
IN	PA	2	6012	4865	64.9	63.3	8.7	5.2	<0.001	Yes

$$H_0 : \tilde{I}_{s1} - \tilde{I}_{s2} \geq I_T \quad (1)$$

$$H_a : \tilde{I}_{s1} - \tilde{I}_{s2} < I_T \quad (2)$$

8.2. Truck Space Mean Speeds

A similar set of null and alternate hypotheses were developed for space mean speeds as presented by Equations (3) and (4) below. Results of the tests in Table 6 observed statistical significance rejecting the null hypothesis in favor of the alternate hypothesis, pointing to median space mean speeds for Illinois being less than 2 mph higher than those for Indiana, and those for Ohio being less than 1 mph higher than Indiana.

$$H_0 : \tilde{S}_{s1} - \tilde{S}_{s2} \geq S_T \quad (3)$$

$$H_a : \tilde{S}_{s1} - \tilde{S}_{s2} < S_T \quad (4)$$

9. Conclusions

This study utilized connected truck data to observe truck speeds on the I-70 corridor through the states of Illinois, Indiana, Ohio, West Virginia and Pennsylvania for a one-week period from May 8-14, 2022. Linearly referenced truck speeds visualized at the one mile and 20-mile aggregated level showed significant speed drops on portions of the corridor passing through urban areas (Figure 4 and Figure 5). Four 20-mile sections in the states of Illinois, Indiana, Ohio and Pennsylvania were chosen for an instantaneous and space mean speed comparison to quantify whether DSLs in Indiana had a discernible impact on truck speeds compared to USLs in Illinois, Ohio and Pennsylvania. Statistical tests for these 20-mile sections clearly show that a DSL policy in Indiana has minimal impact on truck speeds. Instantaneous and space mean speeds for trucks in Indiana only show a 1 - 2 mph deficit from those observed in the neighboring states of Illinois and Ohio (**Table 5**, **Table 6**). Hence, a regulatory speed limit gap of 5 mph between DSL in Indiana and USL in Illinois, Ohio results in only a 1 - 2 mph gap in actual observed truck speeds.

This analysis can be easily scaled and repeated for any corridor as the connected truck data is not limited by infrastructure needs of traditional spot speed, Bluetooth matching or license plate matching data collection techniques that are time and labor intensive. As freight mobility and automated truck investment start to ramp up, connected truck data presents stakeholders with a unique opportunity towards informing regulatory decision-making such as setting speed limits and assigning dedicated truck lanes among others.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: D. M. Bullock, J. Desai, J. K. Mathew, H. Li; data collection: H. Li; analysis and interpretation of results: D. M. Bullock, J. Desai, J. K. Mathew, H. Li; draft manuscript preparation: D. M. Bullock, J. Desai, J. K. Mathew, H. Li. All authors reviewed the results and approved the final version of the manuscript.

Conflicts of Interest

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

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