

# EXPLORING THE IMPACT OF ROADWAY LIGHTING ON DRIVER BEHAVIOR AND ROAD SAFETY

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## ABSTRACT

**Objectives:** This work examines how roadway lighting affects speed patterns, speeding behaviors, and crash outcomes. The objective is to quantify the operational and safety effectiveness of lighting as a countermeasure across different road classes and facility types.

**Methods:** This study constructs citywide speed and speeding-share models in Austin, Texas, using 2.39 million segment-level probe vehicle observations, and estimates intersection and midblock crash models using 2016–2025 police-reported crash data. In addition, this paper evaluates 43 treated and 57 control sites before and after lighting installation across Texas to identify effectiveness.

**Findings:** Each additional light pole per mile was associated with 0.04 mph lower mean speeds on locals and collectors beyond the baseline effect, suggesting that lighting is more effective at reducing nighttime speeds on lower-class roadways. Speeding-share models show that the effect of additional light poles on speeding shares is small on higher-class roads. In addition, added intersection lighting lowers nighttime crash rates while delivering significant crash-reduction benefits for vulnerable road users (VRUs).

**Novelty:** Unlike previous studies, this work examines the relationship between lighting and speeding behavior at the regional scale and evaluates the operational and safety effectiveness for VRUs.

**Practical Application:** This work underscores that roadway lighting is effective in improving nighttime intersection safety, particularly for VRUs. Implementation should prioritize lighting upgrades on local roads and at urban intersections where VRU activity is concentrated.

Total Number of Pages: 20

## 1 BACKGROUND

2 Lighting conditions are a significant factor affecting driver behavior and road safety. According to the  
3 Federal Highway Administration (FHWA, 2021), although only 25% of vehicle-miles traveled (VMT)  
4 occur at night, the nighttime fatality rate is three times that of the daytime rate. In 2023, 75% of the 7,314  
5 pedestrian fatalities in the U.S. occurred between 6 p.m. and 6 a.m. (IIHS, 2025), and pedestrians injured  
6 in the dark were found to be five times more likely to be killed than those injured during the day (Ferenchak  
7 et al., 2022). Improved visibility enables drivers and other road users to better perceive traffic conditions  
8 and to drive, walk, or bike more safely (Hills, 1980; Wood, 2020). Therefore, roadway lighting is widely  
9 used as a safety countermeasure to reduce the incidence of nighttime crashes.

10 Many past studies (e.g., Makela and Karki, 2004; Jägerbrand and Sjöbergh, 2016; Gilandeh et al., 2018)  
11 have examined the relationship between roadway lighting and vehicle speeds. For instance, Assum et al.  
12 (1999) compared 273,780 vehicle speeds three weeks before and four weeks after the installation of  
13 roadway lighting on a highway section in Norway and found that vehicle speeds rose 3% to 5% (as  
14 compared to speeds along unlighted, nearby control sections, at the same time, under same weather and  
15 traffic load conditions). In contrast, Reed and Woodard (1981) investigated average speeds of 80 vehicles  
16 with highway lighting turned on and off along a 0.75-mile section of a state highway in Colorado and found  
17 that lighting did not significantly change mean speeds. Jägerbrand and Sjöbergh (2016) reported similar  
18 findings. They examined 60 million hourly vehicle speed observations over a two-year period at 25  
19 locations in Sweden, of which 17 were equipped with roadway lighting. They collected data under different  
20 light conditions (daylight, twilight, darkness, and artificial light) as well as various weather conditions (clear  
21 weather, rain, and snow). Results showed that vehicle speeds and speed differences between daylight and  
22 darkness, with and without road lighting, did not differ significantly. However, they pointed out that the  
23 reduction in average speeds due to rain or snow was greater on roads without lighting. Patella et al. (2020)  
24 measured vehicle speeds as they entered the 65-meter (0.04-mile) zone before the zebra crosswalk section  
25 on an urban road segment in the city of Rome. Of the 200 speed observations collected, half were collected  
26 under non-illuminated conditions. They found that mean vehicle speeds decreased by 19.3% at the  
27 crosswalk section under illuminated conditions.

28 While previous literature reports mixed effects of roadway lighting on vehicle speeds, it has been found to  
29 help reduce crash frequency and severities, especially for pedestrian- and cyclist-related crashes (Elvik,  
30 1995; Bruneau et al., 2001; Wanvik, 2009; Obeidat et al., 2022). Elvik (1995) summarized 37 studies across  
31 11 countries and concluded that adding road lighting reduced fatal crashes by 65% and injury crashes by  
32 30%. Bruneau et al. (2001) analyzed crash records from 1990 to 1998 for 213 roadway sections along 500  
33 miles of four-lane rural freeways in Canada and found that continuous lighting was associated with 33%  
34 fewer total crashes than roads without lighting and 32% fewer than roads with interchange-only lighting.  
35 While roadway lighting may affect some drivers' speeds, it enhances visibility so much that it tends to  
36 improve nighttime safety for all road users. Increased lighting not only makes it easier for drivers to see  
37 pedestrians but improves pedestrians' abilities to see their surroundings and detect trip hazards (FHWA,  
38 2026). For instance, Høye (2014) found that road lighting reduced fatal pedestrian crashes in darkness by  
39 78% and injury crashes by 51%, based on 53 meta-analyses of research from around the globe. Using  
40 pedestrian crossing injury data, Siddiqui et al. (2006) constructed an ordered-probit model based on crash  
41 data from 1986 to 2003 and found that street lighting lowered the probability of fatal pedestrian injuries by  
42 42% at midblock crossings and 54% at intersections, compared to dark conditions without street lighting.  
43 In terms of cyclist injuries, Kim et al. (2007) analyzed police-reported crashes in North Carolina over five  
44 years and concluded that darkness without streetlights more than doubled the probability of fatal injuries in  
45 accidents for cyclists compared to accidents occurring in daylight or darkness with streetlights. Li et al.  
46 (2020) studied 242 intersections across Virginia and estimated the benefit-cost ratio (BCR) of lighting  
47 additions at unsignalized intersections to range from 2.6 to 5.6, and 2.8 to 7.9 at signalized intersections,  
48 assuming one injury nighttime crash per year at such locations and no time savings included. They estimated  
49 that the total cost for a new pole, including installation, construction engineering inspection, annual  
50 electricity, and maintenance, was nearly \$45k, compared to \$19k for extending an existing pole.

In real-world scenarios, the decision to install lighting and the appropriate lighting level are two key considerations in the design of lighting systems. The FHWA Lighting Handbook (2023) provides guidelines for policymakers and the design community when considering roadway or street lighting system. For example, in Texas, roadway lighting can only be installed on eligible highways, as defined by state rules (TxDOT, 2018), and city, county and state engineers rely on the AASHTO Roadway Lighting Design Guide (AASHTO, 2018) to justify the need for lighting based on traffic volume, safety studies, and functional classification. To enhance road safety, cities like Austin (Shen, 2024) and Rowlett (Fonroche Lighting America, 2025) in Texas, have installed or upgraded lighting on roads that are prone to crashes. For instance, in 2025, the City of Austin invested \$1.7 million to improve street lighting across 14 intersections, focusing on areas with high crash frequencies and pedestrian activity (Shen, 2024).

However, existing research on the speed and safety effects of roadway lighting has focused on specific road segments rather than examining roadway networks at a regional scale. In addition, few studies have investigated the relationship between extreme speeds (e.g., 85<sup>th</sup> percentile speeds) or speeding behavior and roadway lighting. To address these gaps, this paper uses 2024 INRIX trip trajectory data from individual vehicles (Li and Kockelman, 2026) and detailed lighting data from the City of Austin to analyze speed and speeding patterns on roadways with and without lighting across the city. The study then retrieves crash data from 2016 to 2025 for the city and models intersection and midblock crash rates as a function of lighting and other attributes. Finally, it examines 43 treated and 57 control corridors on non-freeways across multiple cities in Texas before and after lighting treatment installation using a Difference-in-Differences framework, evaluating both operational and safety effectiveness of lighting for all road users, especially for pedestrians and cyclists.

## **PRELIMINARY DATA ANALYSIS**

This section provides a detailed description of the INRIX probe vehicle data, roadway lighting data from the City of Austin, city crash data over the past ten years (2016 to 2025), and INRIX speed data for 43 treated sites and 57 control sites across the state used in the work.

### **INRIX Probe Vehicle Data**

INRIX's 2024 trip data provide 2 to 4 million vehicle trajectories per day in Texas (which represents 3% to 4% of all trips), along with trip distance and duration (between engine on and off points), trip start and end times, and detailed trajectory tracking by segment ID. Due to the large volume of data, this study utilized a one-month sample from November 1 to November 30, 2024, which is the most recent period available under the TxDOT license. Because INRIX data are derived from connected vehicles equipped with in-vehicle GPS systems, they are subject to sampling bias and may not perfectly represent the full vehicle fleet. Relative to national VMT shares, light-duty and heavy-duty vehicles may be underrepresented, while medium-duty vehicles may be overrepresented in the dataset (Li and Kockelman, 2026).

Each trip record includes a unique trip identifier, total trip distance, trip duration, and timestamps for trip start and end. In addition, each trip trajectory contains an ordered sequence of roadway segments with segment IDs, segment lengths, entry and exit times, and travel speeds. Travel speeds were extracted for each segment and aggregated by hour of day to identify speed and speeding patterns. Trip times are stored in Coordinated Universal Time (UTC) and were converted to local time to identify the hour for analysis. Notably, daylight saving time ended in Austin on November 3, 2024, when clocks moved back by one hour. Figure 1 presents the hourly distribution of INRIX trips on roads in the City of Austin in November 2024. The plot shows that traffic volumes are lowest during overnight hours (1 a.m. to 4 a.m.) and increase rapidly during commute hours.

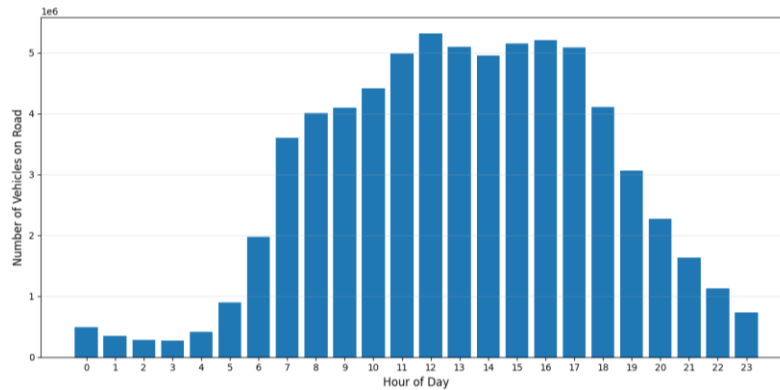


Figure 1: Number of INRIX Vehicles on Roads in the City of Austin by Time of Day in November 2024

### Roadway Lighting Data

Roadway lighting data were obtained from Austin Energy (2026) for the City of Austin (as shown in Figure 2). The dataset includes detailed inventory information for 65,593 light poles distributed across the city and is updated through April 2026. Historical changes in lighting infrastructure over the past ten years are assumed to be minimal in this work, as no major citywide lighting upgrades or replacements were documented during that period.

For each pole, lamp wattage, mounting arm length, lamp type, and illumination direction are provided. Figure 2 illustrates the spatial distribution of roadway light poles, indicating higher pole densities in urbanized and downtown areas. However, tree canopy and other potential visual obstructions are not publicly available, although these factors may influence actual lighting conditions at the roadway level. In addition, the reported pole height refers to the distance from the ground to the top of the utility pole or overhead wire connection, if any, rather than the exact mounting height of the luminaire; therefore, the actual luminaire height is likely lower than the reported value. Under these circumstances, it is difficult to accurately calculate illuminance for each INRIX segment. Therefore, this study uses lighting density, defined as the number of light poles per mile (Uttley et al., 2020), as a proxy indicator of lighting conditions. A 30-ft buffer was used to assign light poles to the corresponding INRIX roadway segments.

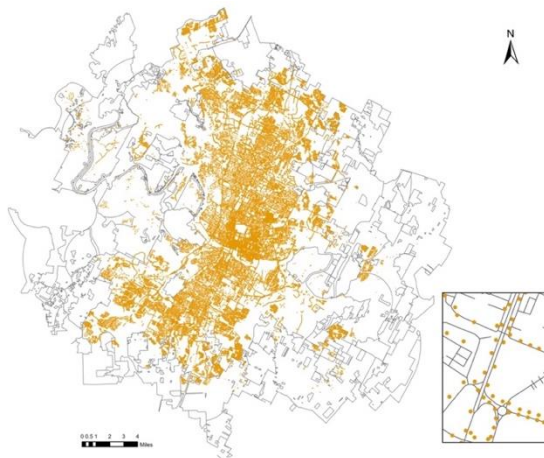


Figure 2: Spatial Distribution of Roadway Lighting in Austin

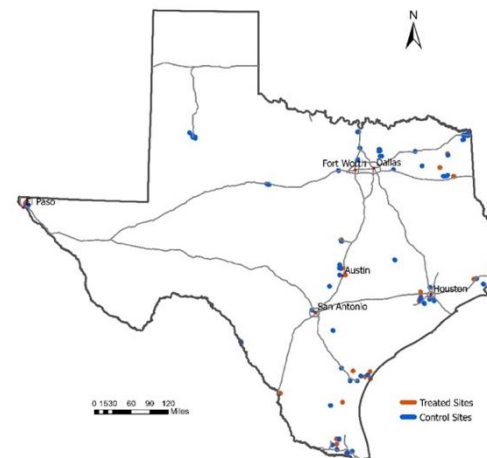


Figure 3: Spatial Distribution of 100 Sites across TX

### City Crash Data

City crash data were extracted from the Crash Records Information System (CRIS) query tool, maintained by TxDOT (2026). The dataset provides comprehensive information on crash time, locations, contributing factors, vehicle types, and any injuries or fatalities involved. This study collects police-reported crashes in the City of Austin from 2016 to 2025, and records with missing latitude or longitude information were

excluded from the analysis. Figure 4 shows the hourly distribution of vulnerable road user (VRU) crashes (pedestrians and cyclists) and total crashes over the ten-year period, and the percentages shown within the bars represent the share of VRU-related crashes among total crashes. Among the 138,827 crashes in the dataset, the highest counts occurred during the afternoon peak hours (e.g., 5 p.m. and 6 p.m.). Besides, VRU-related crash shares were highest during the evening hours from 6 p.m. to 9 p.m., reaching up to 6% of total crashes during the same hour.

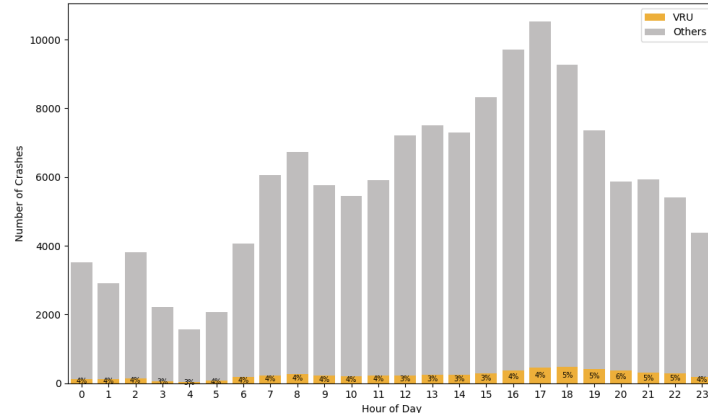


Figure 4: Hourly Distribution of Total and VRU-Related Crashes in City of Austin (2016 to 2025)

For crash models, intersection and midblock crashes were analyzed separately, as midblock crashes tend to be more severe and more common, and most transportation agencies maintain corridor design variables (Roudsari et al., 2007; Zuniga-Garcia et al., 2022; Kwayu et al., 2022). To identify intersections, small INRIX segments were first converted into vertex points in ArcGIS Pro, and a spatial join was then applied to count the number of segments connected to each node. Nodes with three or more connected segments were classified as intersections. Intersection crashes were identified based on the Intersection flag in CRIS records, and 57,013 crashes (41.07% of all crashes) were classified as intersection-related, while the remaining crashes were classified as midblock crashes. The detailed model is introduced in the next section.

### Case Study Data

This work collects information on 100 corridors on non-freeways across the state (including location, roadway design attributes, traffic volumes, speeds and crash counts by type) for further analysis and 43 of these added lighting. For all sites, the start of the “before” period was defined as January 1, 2018, and the end of the “after” period was defined as December 31, 2025. Installation dates for each treated study site were obtained from local agency personnel. Sites with posted speed limits (PSLs) of 60 mph or higher, which are typically not non-freeway facilities, and sites with unknown construction or installation dates were excluded from this study. For each treated site, control sites were selected based on four criteria: 1) both sites have the same number of lanes, 2) both sites have the same PSLs, 3) the Annual Average Daily Traffic (AADT) values of both sites are within a 20% range, and 4) the segment length is at least 0.25 miles. Appendix 1 lists all treated and control sites and their key characteristics, including the number of lanes, PSL, and AADT values. AADT values were extracted from the TxDOT Roadway Inventory dataset (TxDOT, 2026), while the number of lanes and PSL were obtained from Google Street View imagery. Notably, when a treatment is implemented along a continuous corridor, but roadway characteristics (like PSL) vary across segments, the corridor was divided into multiple segments. This ensures that each study site has consistent values for PSL and the number of lanes. Figure 3 presents the distribution of the 100 sites in the case study.

Lighting treatments are active only during nighttime periods. Sunrise and sunset times were determined for study sites based on each site’s geographic coordinates (latitude and longitude) and using the Python language’s Astral package for each day and year. For instance, at the Light-1 site, the segment centroid coordinates are 30.314884 and -97.702756, so sunrise on January 1, 2018, was at 07:27:42 (CST), and sunset was at 17:41:23 (CST). Therefore, the lighting treatment was active only during that 10.24-hour

period. Before-and-after vehicle speed data used in this section were obtained from the RITIS Probe Data Analytics tool under TxDOT's license, using INRIX XD segments. XD segments are an INRIX-proprietary road segmentation system that divides roadways at intersections and other key geometric points (INRIX, 2026). For each XD segment, average speeds were computed as the harmonic mean of all observed speeds during the selected time period. The final speed dataset for lighting includes 30.8 million hourly segment-level observations for 43 treated sites and 57 control sites. Given the large size of the dataset, and because vehicle counts and speeds do not differ significantly across the same combinations of day of week, month, and year (e.g., the first Monday in January 2018 versus the second Monday in January 2018), the data were aggregated at the segment level within each unique combination of these temporal dimensions, resulting in a final dataset of 7.1 million observations. On the other hand, crash data were extracted within a 250-ft buffer of each corridor using the CRIS query tool, and 27,263 crashes were collected for analysis.

## METHODOLOGY

This section describes the speed and speeding-share models at the segment-hour level in the City of Austin, as well as crash count models for intersections and midblocks. After that, a Difference-in-Differences framework applied to 100 sites across the entire state is presented.

### Speed and Speeding-share Models

Segment-level vehicle speeds were integrated with PSLs to quantify speeding patterns, represented by the percentage of vehicle exceeding the PSL, as well as the percentages exceeding it by more than 15% and 30%. Because the INRIX trip trajectory dataset is tied to an internal INRIX roadway network and does not include roadway attributes or land-use information, it was spatially joined with the TxDOT Roadway Inventory Dataset (2026) and the Texas Education Agency Dataset (2025) to incorporate roadway characteristics and identify whether a school was located within a 0.25-mile buffer of each segment. In addition, the EPA Smart Location Database (2021) was used to obtain land-use characteristics of the nearest block group for each INRIX segment. The final dataset includes 14,769 INRIX segments in the City of Austin and a total of 2.39 million records for analysis (observations with 95<sup>th</sup> percentile speeds below 5 mph were removed).

Lighting density was calculated for each INRIX segment as the number of roadway light poles per mile. The model includes a nighttime indicator variable to distinguish observations occurring during nighttime hours, a lighting density variable to capture the baseline association between lighting and speeds, and an interaction term between lighting density and nighttime conditions to quantify whether the effects of lighting on vehicle speeds or speeding behavior differ at night relative to daytime conditions. Each data record represents vehicle speeds and speeding behavior on a specific segment during a given hour. Table 1 presents summary statistics for the dataset and related characteristics. Other explanatory variables (e.g., lane width) were not statistically significant and were therefore omitted from final results. To account for spatial autocorrelation, a spatial weight matrix was constructed using  $w_{ij} = 1/d_{ij}$ , where  $d_{ij}$  represents the distance between roadway segment centroids within 1 mile of each other. WLS and a spatially weighted binomial logistic model were used to estimate the relationship between segment-level vehicle speeds (average, 85<sup>th</sup> percentil, and 95<sup>th</sup> percentile speed) and segment-level speeding behavior (percentages of vehicles exceeding the PSL, exceeding it by more than 15%, and exceeding it by more than 30%), respectively. The formula for the binomial logistic model for each segment  $i$  is provided below:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 Night_i + \beta_2 Lighting\ Density_i + \beta_3 Night_i \times Lighting\ Density_i + \beta_4 X_4 \dots + \beta_N X_N, \text{ with weights } w_i$$

where  $p$  = percentage of vehicles exceeding the PSL, or exceeding it by more than 15% or 30% (depending on the model run). To evaluate the magnitude of each variable's impact on speeds and speeding shares, practical significance was calculated by increasing each covariate by one standard deviation (SD) and estimating the ratio of speeds/speeding-shares after to that before the increase.

Table 1: Summary Statistics for Speed and Roadway Data in the City of Austin (n=2.39M)

| Variable               | Description                                                                             | Mean | Med  | S.D. | Min  | Max  |
|------------------------|-----------------------------------------------------------------------------------------|------|------|------|------|------|
| Avg Speed              | Average vehicle speed within the segment during the hour (miles/hour = mph)             | 33.1 | 29.7 | 15.9 | 1.55 | 117  |
| 85 <sup>th</sup> Speed | 85 <sup>th</sup> percentile vehicle speed within the segment during the hour (mph)      | 40.3 | 37.1 | 17.0 | 1.83 | 120  |
| 95 <sup>th</sup> Speed | 95 <sup>th</sup> percentile vehicle speed within the segment (mph)                      | 44.1 | 41.6 | 17.8 | 5    | 120  |
| % over PSL             | % of vehicles driving over PSLs within the segment during the hour                      | 0.22 | 0.07 | 0.29 | 0    | 1    |
| % over 15PSL           | % of vehicles driving over PSLs by more than 15% within the segment during the hour     | 0.09 | 0    | 0.20 | 0    | 1    |
| % over 30PSL           | % of vehicles driving over PSLs by more than 30% within the segment during the hour     | 0.04 | 0    | 0.14 | 0    | 1    |
| Night                  | 1 if observed during nighttime (6 p.m. to 7 a.m. in November 2024), 0 otherwise         | 0.43 | 0    | 0.50 | 0    | 1    |
| Light Dens.            | Number of roadway lighting poles per mile                                               | 11.5 | 0    | 23.1 | 0    | 259  |
| Night x Light          | Interaction between nighttime and lighting pole density                                 | 5.25 | 0    | 16.7 | 0    | 259  |
| Local                  | 1 if the segment is a local road, 0 otherwise                                           | 0.12 | 0    | 0.33 | 0    | 1    |
| Collector              | 1 if the segment is a collector, 0 otherwise                                            | 0.47 | 0    | 0.50 | 0    | 1    |
| Arterial               | 1 if the segment is an arterial, 0 otherwise                                            | 0.41 | 0    | 0.49 | 0    | 1    |
| Tuesday                | 1 if observed on Tuesdays, 0 otherwise                                                  | 0.14 | 0    | 0.35 | 0    | 1    |
| Wednesday              | 1 if observed on Wednesdays, 0 otherwise                                                | 0.14 | 0    | 0.35 | 0    | 1    |
| Thursday               | 1 if observed on Thursdays, 0 otherwise                                                 | 0.14 | 0    | 0.35 | 0    | 1    |
| Friday                 | 1 if observed on Fridays, 0 otherwise                                                   | 0.15 | 0    | 0.36 | 0    | 1    |
| Saturday               | 1 if observed on Saturdays, 0 otherwise                                                 | 0.15 | 0    | 0.35 | 0    | 1    |
| Sunday                 | 1 if observed on Sundays, 0 otherwise                                                   | 0.14 | 0    | 0.35 | 0    | 1    |
| Urban                  | 1 if the segment is in urban area (pop > 5k), 0 otherwise                               | 0.98 | 1    | 0.13 | 0    | 1    |
| School within ¼ mile   | 1 if the segment is within ¼ mi of a K12 school, 0 otherwise                            | 0.15 | 0    | 0.35 | 0    | 1    |
| Two-Way                | 1 if the segment is two-way, 0 one-way                                                  | 0.62 | 0.49 | 1    | 0    | 1    |
| Median                 | 1 if the segment has a median (a TWLTL is not considered as a median here), 0 otherwise | 0.27 | 0    | 0.44 | 0    | 1    |
| # Lanes                | Number of lanes per direction on the segment                                            | 2.05 | 2    | 0.95 | 1    | 6    |
| Counts per Lane        | Number of vehicles per lane per direction on this segment during the hour               | 14.3 | 5.33 | 26.4 | 0.13 | 745  |
| Speed Limit            | PSL of the segment (mph)                                                                | 44.2 | 40   | 13.8 | 10   | 85   |
| Pop Dens.              | Population density per acre in nearest block group (BG)                                 | 5.64 | 5.12 | 4.86 | 0    | 90.3 |
| Job Dens.              | Jobs per acre in nearest BG                                                             | 8.96 | 2.33 | 21.5 | 0    | 120  |
| Network Dens.          | Road network density per square miles in nearest BG                                     | 19.2 | 19.2 | 10.6 | 1.89 | 45.2 |
| Ped Road Dens.         | Facility miles of pedestrian-oriented links per square miles in nearest BG              | 11.2 | 10.5 | 6.81 | 0.02 | 42.0 |
| Intersection Dens.     | Street intersection density per square miles in nearest BG                              | 75.7 | 52.9 | 66.3 | 0    | 864  |
| Ped Intersect Dens.    | Pedestrian-oriented intersections having 4+ legs per square miles in the nearest BG     | 17.9 | 7.69 | 23.3 | 0    | 292  |
| Walk Score             | Walkability score out of 20 of the nearest BG                                           | 11.7 | 12   | 4.31 | 2.8  | 20   |

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Sources: Speed data are from INRIX (Nov. 4-10, 2024). Roadway lighting data are from Austin Energy (2026). Road attributes are from TxDOT's Roadway Inventory Dataset (2026). School data are from the Texas Education Agency (2025). And land use data for the nearest block group are from the US EPA's Smart Location Database (2021).

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## Intersection and Midblock Crash Count Models

As crash count data are non-negative and exhibit overdispersion, Negative Binomial (NB) regression models were used for both intersection and midblock crash models. Roadway lighting at intersections was measured as the total number of light poles located within the 50-ft intersection buffer. Unlike midblock crashes, both major-approach and minor-approach roadway characteristics were included in the intersection model. The major approach was identified as the connecting segment with higher AADT value, PSL, and number of lanes. Signal control information for the City of Austin was obtained from the City of Austin (2026) to identify whether each intersection was signalized. For midblock crashes, consistent with previous speed models, lighting was represented by roadway lighting density.

To distinguish daytime and nighttime crashes, sunrise and sunset times for each crash date in Austin were retrieved using the Astral package. A nighttime indicator variable was assigned to crashes occurring after sunset or before sunrise. The final dataset consists of 36,058 intersections and 37,016 segments for the intersection and midblock crash models, respectively, and was structured with two observations per intersection or segment, corresponding to daytime and nighttime crash counts. Daytime and nighttime AADT values were estimated by applying time-of-day traffic proportions, with nighttime traffic assumed to represent 25% of daily traffic volumes based on FHWA's (2014) estimate. The general specification of the models is as follows:

For intersection crash counts:

$$\log(\mu_{i,t}) = \beta_0 + \beta_1 \text{Night}_{i,t} + \beta_2 \text{Light Density}_i + \beta_3 \text{Night}_{i,t} \times \text{Light Density}_i \\ + \beta_4 \log(\text{AADT}_{\text{major},i,t}) + \beta_5 \log(\text{AADT}_{\text{minor},i,t}) + \beta_6 X_6 \dots + \beta_N X_N$$

For midblock crash counts:

$$\log(\mu_{i,t}) = \beta_0 + \beta_1 \text{Night}_{i,t} + \beta_2 \text{Light Density}_i + \beta_3 \text{Night}_{i,t} \times \text{Light Density}_i \\ + \beta_4 \log(\text{AADT}_{i,t} \cdot \text{Length}_i) + \beta_6 X_6 \dots + \beta_N X_N$$

Where,  $\mu_i$  = crash count at intersection  $i$  or road segment  $i$  during time period  $t$  (daytime or nighttime). Other variables (e.g., median width) were not statistically significant and were therefore removed.

## Difference-in-Differences (DiD) Model

To estimate the speed and crash effects of lighting, a Generalized Least Squares (GLS) regression model with site-level random effects and a Generalized Linear Mixed Model (GLMM) were developed, respectively. For the speed model, the dependent variable is the average vehicle speed observed at each segment during each hourly interval aggregated by day of week during the same month and year. Control variables include indicator variables representing the active operation of lighting as a safety countermeasure. Specifically, the lighting treatment was divided into three periods: from sunset to 11 p.m., from 11 p.m. to 2 a.m., and from 2 a.m. to sunrise. This temporal segmentation allows the model to capture potential differences in vehicle speeds during late-night activity and after bar closing hours, when driving risks may change. In terms of other variables used in the model, pedestrian and cyclist activity were represented using walk-miles traveled (WMT) and bike-miles traveled (BMT) densities, derived from tract-level estimates developed by Li and Kockelman (2025). For segments that traverse multiple tracts, WMT and BMT values were apportioned based on the intersection area. Land use variables, such as vehicle ownership, population density, and job density for the block group to each road segment, were calculated by constructing a 0.25-mile buffer around each segment and apportioning them accordingly. Weather can also have a significant influence on vehicle speeds; therefore, the Analysis of Record for Calibration (AORC) dataset (2026) was used to obtain weather information by location and time. Additional physical roadway and infrastructure characteristics were extracted from Google Street View imagery for periods before and after treatment. Notably, the TxDOT Roadway Inventory dataset (2026) provides AADT values for each segment. However, these values remain constant throughout the day, which is unrealistic given that early-morning traffic flow is typically much lower. To address this, INRIX probe data in November 2024 was used here

to distribute AADT values into hourly real-time traffic flows for all segments. The total number of vehicles passing through each segment was counted hourly, and hourly traffic flow was scaled based on the ratio of hourly counts to the total sample, ensuring that the sum of the hourly flows equals the provided estimated AADT values.

Time fixed effects capture common temporal factors affecting all sites, including year, month, day, and hour. As the dependent variable is hourly speed, the variability of observed speeds differs across hours of day, days of the week, and road segments, leading to possible heteroskedasticity across observations. To address this issue and the possible correlation between the same treated-control pair, standard errors were clustered at the treated-control group level. The equation is listed below:

$$Speed_{i,t} = \beta_0 + \beta_1 Lighting_{sunset-11,i,t} + \beta_2 Lighting_{11-2,i,t} + \beta_3 Lighting_{2-sunrise,i,t} + X_{i,t}\alpha + Z_i\beta + \gamma_t + u_i + \epsilon_{i,t}$$

Where,  $Speed_{i,t}$  is the hourly average speeds at segment  $i$  and time  $t$ ,  $Lighting_{11-2,i,t}$  and  $Lighting_{2-sunrise,i,t}$  are indicators representing the active operation of lighting during specific time periods,  $X_{i,t}$  is the vector of time-varying covariates (e.g., weather conditions, traffic flow, etc.),  $Z_i$  is the vector of time-invariant covariates (e.g., roadway characteristics, land use, etc.),  $\gamma_t$  represents time fixed effects,  $u_i$  is the site-level random effect, and  $\epsilon_{i,t}$  is the error term.

Unlike the millions of hourly speed observations in the speed model, the crash data consist of crash rates aggregated over the before and after periods, resulting in two rows per site. Therefore, the GLMM model incorporates site-level random effects to account for baseline site heterogeneity and clustered observations within treated-control pairs. In addition, the model includes a random intercept for each site to capture unobserved site-specific factors that are constant over time. Baseline site heterogeneity is further controlled by roadway and land-use variables. The expected number of crashes is modeled as:

$$\ln(\mu_{i,t}) = \beta_0 + \beta_1 Treatment_{i,t} + \beta_2 Treated_i + \beta_3 After_t + \beta_4 \ln(Tot\_VMT_{i,t}) + Z_i\beta + u_i + \epsilon_{i,t}$$

Where,  $\mu_{i,t}$  is the crash count,  $Treatment_{i,t}$  is a binary indicator representing treatment (1 if the site is treated and in the after period),  $Treated_i$  indicates treated or control groups,  $After_t$  indicates the before or after period,  $Tot\_VMT_{i,t}$  represents Vehicle Miles Traveled  $\times$  days during the operational period to account for variations in traffic volumes and the duration of the before and after periods,  $Z_i$  is the vector of time-invariant covariates (e.g., roadway characteristics, land use, etc.),  $u_i$  is the site-level random effect, and  $\epsilon_{i,t}$  is the error term.

## RESULTS

This section presents the model estimation results for the speed and speeding-share models, the intersection and midblock crash count models, and the Difference-in-Differences analysis. Key findings on the effects of roadway lighting on vehicle speeds, speeding behavior, and safety outcomes are discussed.

### Speed and Speeding-share Model Results

Table 2 presents the speed model estimates for local roads, collectors, and arterials. Across all road classes, PSL remained the strongest predictor of operating speeds, with a 1-mph increase in PSL associated with increases ranging from 0.56 to 0.71 mph in average speed, 0.59 to 0.95 mph in 85th percentile speed, and 0.60 to 0.98 mph in 95th percentile speed, depending on the road class. Other roadway design characteristics also exhibited varying effects by road class. On local roads, two-way configurations and additional lanes were associated with significantly higher speeds (4.95 mph and 2.47 mph per lane, respectively), while urban location reduced average speeds by 1.04 mph. On collectors, urban location had a strong negative effect on average speeds (-8.22 mph), while two-way roads showed only a modest positive effect. On arterials, two-way configurations and more lanes were associated with lower speeds (-2.44 mph and -1.71 mph per lane, respectively), indicating more constrained urban arterial environments. In addition, denser and more pedestrian-oriented areas tend to have lower speeds on arterials and collectors, but show mixed effects on local roads. For example, a one-SD increase in network density was associated with a 17.8%

increase in average speeds on arterials, but a 7.4% decrease on local roads. Higher walkability scores were associated with lower speeds on collectors and arterials.

Nighttime conditions were consistently associated with higher speeds across all road types, with the largest increases observed on arterials (5.05 mph in average speed), followed by collectors (3.46 mph) and local roads (2.43 mph). The interaction between nighttime and lighting density revealed additional speed reductions at night for all road classes, particularly for collectors and local roads (0.04 mph reduction for each additional light pole per mile), suggesting that lighting is more effective at reducing nighttime speeds on lower-class roadways.

Table 2: WLS Model Estimates for Average, 85<sup>th</sup> Percentile, and 95<sup>th</sup> Percentile Speeds

| Variable                 | Y = Avg speed in INRIX |         |             | Y = 85 <sup>th</sup> Percentile speed |         |             | Y = 95 <sup>th</sup> Percentile speed |         |             |
|--------------------------|------------------------|---------|-------------|---------------------------------------|---------|-------------|---------------------------------------|---------|-------------|
|                          | Coef.                  | Std Err | Pract. Sign | Coef.                                 | Std Err | Pract. Sign | Coef.                                 | Std Err | Pract. Sign |
| LOCAL ROADS (N=292,527)  |                        |         |             |                                       |         |             |                                       |         |             |
| Constant                 | -4.679                 | 0.248   |             | -9.856                                | 0.275   |             | -11.13                                | 0.294   |             |
| Night                    | 2.427                  | 0.039   | 9.0%        | 1.421                                 | 0.043   | 4.7%        | 0.974                                 | 0.046   | 3.1%        |
| Light Dens.              | -0.010                 | 0.002   | -0.4%       | -0.023                                | 0.002   | -0.7%       | -0.028                                | 0.002   | -0.8%       |
| Night x Light            | -0.043                 | 0.003   | -0.9%       | -0.037                                | 0.004   | -0.7%       | -0.036                                | 0.004   | -0.6%       |
| Tuesday                  | -0.079                 | 0.060   | -0.3%       | 0.047                                 | 0.067   | 0.2%        | 0.108                                 | 0.071   | 0.3%        |
| Wednesday                | -0.296                 | 0.060   | -1.1%       | -0.176                                | 0.066   | -0.6%       | -0.115                                | 0.071   | -0.4%       |
| Thursday                 | 0.159                  | 0.060   | 0.6%        | 0.173                                 | 0.067   | 0.6%        | 0.209                                 | 0.071   | 0.7%        |
| Friday                   | -0.461                 | 0.058   | -1.7%       | -0.288                                | 0.065   | -1.0%       | -0.160                                | 0.069   | -0.5%       |
| Saturday                 | -0.026                 | 0.059   | -0.1%       | 0.007                                 | 0.065   | 0.0%        | 0.046                                 | 0.070   | 0.2%        |
| Sunday                   | 0.839                  | 0.062   | 3.1%        | 0.572                                 | 0.068   | 1.9%        | 0.472                                 | 0.073   | 1.5%        |
| Urban                    | -1.035                 | 0.088   | -3.8%       | 0.038                                 | 0.098   | 0.1%        | 0.565                                 | 0.104   | 1.8%        |
| School within ¼ mile     | -0.095                 | 0.044   | -0.4%       | 0.492                                 | 0.049   | 1.6%        | 0.850                                 | 0.053   | 2.7%        |
| Two-Way                  | 4.949                  | 0.161   | 18.3%       | 4.689                                 | 0.179   | 15.5%       | 3.856                                 | 0.191   | 12.3%       |
| # Lanes                  | 2.465                  | 0.088   | 1.6%        | 4.252                                 | 0.098   | 2.4%        | 4.867                                 | 0.105   | 2.6%        |
| Counts per Lane          | 0.081                  | 0.001   | 4.8%        | 0.122                                 | 0.001   | 6.4%        | 0.148                                 | 0.002   | 7.5%        |
| Speed Limit              | 0.713                  | 0.003   | 21.1%       | 0.891                                 | 0.003   | 23.6%       | 0.960                                 | 0.003   | 24.5%       |
| Pop Dens.                | 0.052                  | 0.010   | 0.5%        | 0.030                                 | 0.012   | 0.3%        | -0.003                                | 0.012   | -0.0%       |
| Job Dens.                | -0.014                 | 0.012   | -0.1%       | 0.091                                 | 0.013   | 0.5%        | 0.155                                 | 0.014   | 0.9%        |
| Network Dens.            | -0.362                 | 0.010   | -7.4%       | -0.354                                | 0.011   | -6.5%       | -0.348                                | 0.012   | -6.1%       |
| Ped Road Dens.           | 0.176                  | 0.013   | 3.1%        | 0.121                                 | 0.014   | 1.9%        | 0.098                                 | 0.015   | 1.5%        |
| Intersection Dens.       | 0.009                  | 0.002   | 1.0%        | 0.017                                 | 0.002   | 1.6%        | 0.024                                 | 0.002   | 2.2%        |
| Ped Intersect Dens.      | -0.020                 | 0.005   | -0.4%       | -0.027                                | 0.006   | -0.5%       | -0.039                                | 0.006   | -0.7%       |
| Walk Score               | 0.230                  | 0.008   | 2.1%        | 0.216                                 | 0.009   | 1.8%        | 0.196                                 | 0.010   | 1.5%        |
| R <sup>2</sup>           | 0.306                  |         |             | 0.363                                 |         |             | 0.375                                 |         |             |
| Log-Lik                  | -1.091e+06             |         |             | -1.121e+06                            |         |             | -1.141e+06                            |         |             |
| ρ̂                       | 0.564                  |         |             | 0.576                                 |         |             | 0.566                                 |         |             |
| COLLECTORS (N=1,122,454) |                        |         |             |                                       |         |             |                                       |         |             |
| Constant                 | 19.06                  | 0.298   |             | 23.97                                 | 0.323   |             | 26.04                                 | 0.358   |             |
| Night                    | 3.459                  | 0.021   | 10.8%       | 2.842                                 | 0.022   | 7.3%        | 2.001                                 | 0.025   | 4.7%        |
| Light Dens.              | 0.007                  | 0.001   | 0.4%        | -0.016                                | 0.001   | -0.7%       | -0.026                                | 0.001   | -1.1%       |
| Night x Light            | -0.049                 | 0.001   | -1.9%       | -0.052                                | 0.001   | -1.6%       | -0.073                                | 0.001   | -2.1%       |
| Tuesday                  | -0.807                 | 0.029   | -2.5%       | -0.990                                | 0.032   | -2.5%       | -1.676                                | 0.035   | -3.9%       |
| Wednesday                | -1.408                 | 0.029   | -4.4%       | -1.019                                | 0.032   | -2.6%       | -1.144                                | 0.035   | -2.7%       |
| Thursday                 | -0.099                 | 0.029   | -0.3%       | -0.261                                | 0.032   | -0.7%       | -0.918                                | 0.035   | -2.1%       |
| Friday                   | -0.769                 | 0.029   | -2.4%       | -0.722                                | 0.031   | -1.9%       | -1.206                                | 0.035   | -2.8%       |
| Saturday                 | -0.014                 | 0.029   | -0.0%       | 0.092                                 | 0.031   | 0.2%        | 0.076                                 | 0.035   | 0.2%        |
| Sunday                   | 0.798                  | 0.029   | 2.5%        | 0.559                                 | 0.032   | 1.4%        | 0.604                                 | 0.035   | 1.4%        |
| Urban                    | -8.223                 | 0.289   | -25.7%      | -7.137                                | 0.313   | -18.3%      | -7.153                                | 0.347   | -16.7%      |
| School within ¼ mile     | 0.655                  | 0.024   | 2.1%        | 0.732                                 | 0.026   | 1.9%        | 0.680                                 | 0.029   | 1.6%        |

|                                                                                                                                                                                                                                                                                                                                                                                               |            |       |       |            |       |       |            |       |       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------|-------|------------|-------|-------|------------|-------|-------|
| Two-Way                                                                                                                                                                                                                                                                                                                                                                                       | 0.391      | 0.034 | 1.2%  | -1.038     | 0.037 | -2.7% | -1.938     | 0.041 | -4.5% |
| # Lanes                                                                                                                                                                                                                                                                                                                                                                                       | -0.533     | 0.015 | -1.3% | -0.265     | 0.016 | -0.5% | 0.275      | 0.017 | 0.5%  |
| Counts per Lane                                                                                                                                                                                                                                                                                                                                                                               | 0.073      | 0.001 | 2.8%  | 0.182      | 0.001 | 5.7%  | 0.257      | 0.001 | 7.3%  |
| Speed Limit                                                                                                                                                                                                                                                                                                                                                                                   | 0.563      | 0.001 | 22.4% | 0.590      | 0.001 | 19.2% | 0.595      | 0.001 | 17.7% |
| Pop Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.112     | 0.002 | -1.8% | -0.109     | 0.002 | -1.4% | -0.048     | 0.003 | -0.6% |
| Job Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.024     | 0.000 | -1.4% | -0.035     | 0.000 | -1.7% | -0.038     | 0.000 | -1.7% |
| Network Dens.                                                                                                                                                                                                                                                                                                                                                                                 | 0.102      | 0.002 | 2.9%  | 0.188      | 0.003 | 4.4%  | 0.222      | 0.003 | 4.8%  |
| Ped Road Dens.                                                                                                                                                                                                                                                                                                                                                                                | 0.169      | 0.004 | 3.6%  | 0.021      | 0.004 | 0.4%  | -0.040     | 0.005 | -0.6% |
| Intersection Dens.                                                                                                                                                                                                                                                                                                                                                                            | -0.011     | 0.000 | -2.2% | -0.006     | 0.000 | -0.9% | -0.006     | 0.000 | -1.0% |
| Ped Intersect Dens.                                                                                                                                                                                                                                                                                                                                                                           | -0.020     | 0.001 | -1.6% | -0.018     | 0.001 | -1.1% | -0.012     | 0.001 | -0.7% |
| Walk Score                                                                                                                                                                                                                                                                                                                                                                                    | -0.597     | 0.005 | -7.0% | -0.674     | 0.005 | -6.5% | -0.643     | 0.006 | -5.6% |
| R <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                | 0.488      |       |       | 0.499      |       |       | 0.466      |       |       |
| Log-Lik                                                                                                                                                                                                                                                                                                                                                                                       | -4.176e+06 |       |       | -4.267e+06 |       |       | -4.383e+06 |       |       |
| ρ̂                                                                                                                                                                                                                                                                                                                                                                                            | 0.836      |       |       | 0.774      |       |       | 0.720      |       |       |
| ARTERIALS (N=974,312)                                                                                                                                                                                                                                                                                                                                                                         |            |       |       |            |       |       |            |       |       |
| Constant                                                                                                                                                                                                                                                                                                                                                                                      | -7.137     | 0.350 |       | -6.792     | 0.348 |       | -6.583     | 0.376 |       |
| Night                                                                                                                                                                                                                                                                                                                                                                                         | 5.045      | 0.026 | 13.9% | 3.833      | 0.026 | 8.6%  | 2.730      | 0.028 | 5.5%  |
| Light Dens.                                                                                                                                                                                                                                                                                                                                                                                   | -0.062     | 0.001 | -5.0% | -0.051     | 0.001 | -3.3% | -0.039     | 0.001 | -2.3% |
| Night x Light                                                                                                                                                                                                                                                                                                                                                                                 | 0.003      | 0.001 | 0.2%  | -0.008     | 0.001 | -0.4% | -0.021     | 0.001 | -0.9% |
| Tuesday                                                                                                                                                                                                                                                                                                                                                                                       | -0.273     | 0.038 | -0.8% | 0.166      | 0.038 | 0.4%  | -0.276     | 0.041 | -0.6% |
| Wednesday                                                                                                                                                                                                                                                                                                                                                                                     | -0.120     | 0.038 | -0.3% | 0.600      | 0.038 | 1.3%  | 0.571      | 0.041 | 1.2%  |
| Thursday                                                                                                                                                                                                                                                                                                                                                                                      | -0.252     | 0.038 | -0.7% | 0.380      | 0.038 | 0.9%  | 0.455      | 0.041 | 0.9%  |
| Friday                                                                                                                                                                                                                                                                                                                                                                                        | -0.493     | 0.038 | -1.4% | 0.022      | 0.038 | 0.1%  | -0.056     | 0.041 | -0.1% |
| Saturday                                                                                                                                                                                                                                                                                                                                                                                      | -0.402     | 0.038 | -1.1% | -0.203     | 0.038 | -0.5% | -0.545     | 0.041 | -1.1% |
| Sunday                                                                                                                                                                                                                                                                                                                                                                                        | 0.467      | 0.038 | 1.3%  | 0.499      | 0.038 | 1.1%  | 0.161      | 0.041 | 0.3%  |
| Urban                                                                                                                                                                                                                                                                                                                                                                                         | -0.805     | 0.335 | -2.2% | 3.044      | 0.334 | 6.8%  | 5.486      | 0.360 | 11.1% |
| School within ¼ mile                                                                                                                                                                                                                                                                                                                                                                          | -0.060     | 0.032 | -0.2% | -0.492     | 0.032 | -1.1% | -0.768     | 0.034 | -1.6% |
| Two-Way                                                                                                                                                                                                                                                                                                                                                                                       | -2.441     | 0.046 | -6.7% | -1.078     | 0.045 | -2.4% | -2.068     | 0.049 | -4.2% |
| Median                                                                                                                                                                                                                                                                                                                                                                                        | 0.144      | 0.040 | 0.4%  | 0.176      | 0.039 | 0.4%  | 1.413      | 0.043 | 2.9%  |
| # Lanes                                                                                                                                                                                                                                                                                                                                                                                       | -1.705     | 0.019 | -4.9% | -0.941     | 0.019 | -2.2% | -0.526     | 0.021 | -1.1% |
| Counts per Lane                                                                                                                                                                                                                                                                                                                                                                               | 0.055      | 0.000 | 5.5%  | 0.070      | 0.000 | 5.7%  | 0.073      | 0.000 | 5.4%  |
| Speed Limit                                                                                                                                                                                                                                                                                                                                                                                   | 0.882      | 0.001 | 35.2% | 0.946      | 0.001 | 30.6% | 0.983      | 0.001 | 28.9% |
| Pop Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.170     | 0.003 | -2.2% | -0.128     | 0.003 | -1.4% | -0.110     | 0.003 | -1.1% |
| Job Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.052     | 0.000 | -3.7% | -0.064     | 0.000 | -3.7% | -0.054     | 0.001 | -2.8% |
| Network Dens.                                                                                                                                                                                                                                                                                                                                                                                 | 0.571      | 0.003 | 17.8% | 0.580      | 0.003 | 14.6% | 0.571      | 0.004 | 13.1% |
| Ped Road Dens.                                                                                                                                                                                                                                                                                                                                                                                | -0.163     | 0.006 | -3.0% | -0.335     | 0.006 | -4.9% | -0.386     | 0.006 | -5.1% |
| Intersection Dens.                                                                                                                                                                                                                                                                                                                                                                            | -0.008     | 0.000 | -1.5% | -0.002     | 0.000 | -0.4% | -0.004     | 0.000 | -0.5% |
| Ped Intersect Dens.                                                                                                                                                                                                                                                                                                                                                                           | -0.048     | 0.001 | -3.0% | -0.034     | 0.001 | -1.7% | -0.025     | 0.001 | -1.2% |
| Walk Score                                                                                                                                                                                                                                                                                                                                                                                    | -0.129     | 0.007 | -1.6% | -0.200     | 0.007 | -2.0% | -0.167     | 0.007 | -1.5% |
| R <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                | 0.739      |       |       | 0.768      |       |       | 0.742      |       |       |
| Log-Lik                                                                                                                                                                                                                                                                                                                                                                                       | -3.855e+06 |       |       | -3.851e+06 |       |       | -3.925e+06 |       |       |
| ρ̂                                                                                                                                                                                                                                                                                                                                                                                            | 0.888      |       |       | 0.837      |       |       | 0.786      |       |       |
| Base: Monday, no access control. Speed data are from INRIX (Nov. 4-10, 2024). Roadway lighting data are from Austin Energy (2026). Road attributes and detailed specifications are from TxDOT’s Roadway Inventory Dataset (2026). School data are from the Texas Education Agency (2025). And land use data for the nearest block group are from the US EPA’s Smart Location Database (2021). |            |       |       |            |       |       |            |       |       |

1 Table 3 shows the estimated results for speeding shares across local roads, collectors, and arterials. Similar  
2 to the speed models, nighttime conditions were strongly associated with higher shares of speeding vehicles  
3 across all thresholds and road classes. The largest nighttime effects were observed on arterials, where the  
4 share of vehicles exceeding the PSL was 51.8% higher at night. The share of speeds exceeding the PSL by  
5 more than 30% was associated with increases of 9.1% on local roads and 1.7% on arterials. The interaction  
6 between nighttime and lighting density varied by road class. On local roads, relative to the baseline daytime  
7 lighting effect, one additional light pole per mile was associated with a 1.6% decrease in nighttime speeding

percentage. However, on collectors and arterials, the impacts of lighting on nighttime speeding were very small. Additionally, lighting had a stronger effect on extreme speeding. Among all other variables, two-way configuration and urban setting were among the most significant factors in the speeding-share models. Land-use variables generally had smaller impacts on speeding shares, while temporal patterns remained notable. For instance, Sunday was associated with a 32.6% higher speeding share compared to Monday.

Table 3: Binomial Logistic Model Estimates for Speeding Shares (Y=% vehicles)

| Variable               | Y = % over PSL |         |             | Y = % over PSL by 15% |         |             | Y = % over PSL by 30% |         |             |
|------------------------|----------------|---------|-------------|-----------------------|---------|-------------|-----------------------|---------|-------------|
|                        | Coef.          | Std Err | Pract. Sign | Coef.                 | Std Err | Pract. Sign | Coef.                 | Std Err | Pract. Sign |
| LOCAL ROADS (N=75,765) |                |         |             |                       |         |             |                       |         |             |
| Constant               | -0.467         | 0.043   |             | -0.371                | 0.066   |             | 0.999                 | 0.100   |             |
| Night                  | 0.404          | 0.008   | 25.7%       | 0.362                 | 0.011   | 21.9%       | 0.370                 | 0.016   | 9.1%        |
| Light Dens.            | -0.011         | 0.000   | -0.7%       | -0.013                | 0.001   | -0.8%       | -0.009                | 0.001   | -0.3%       |
| Night x Light          | -0.016         | 0.001   | -1.0%       | -0.013                | 0.001   | -0.7%       | -0.013                | 0.002   | -0.3%       |
| Tuesday                | -0.032         | 0.011   | -2.0%       | -0.029                | 0.015   | -1.7%       | -0.021                | 0.022   | -0.6%       |
| Wednesday              | -0.060         | 0.011   | -3.7%       | -0.035                | 0.015   | -2.0%       | -0.019                | 0.022   | -0.5%       |
| Thursday               | 0.012          | 0.011   | 0.8%        | 0.032                 | 0.015   | 1.9%        | 0.049                 | 0.022   | 1.3%        |
| Friday                 | -0.062         | 0.010   | -3.8%       | -0.055                | 0.014   | -3.3%       | -0.077                | 0.021   | -2.1%       |
| Saturday               | 0.184          | 0.011   | 11.5%       | 0.185                 | 0.015   | 11.1%       | 0.179                 | 0.021   | 4.6%        |
| Sunday                 | 0.326          | 0.011   | 20.6%       | 0.303                 | 0.016   | 18.3%       | 0.283                 | 0.023   | 7.1%        |
| Urban                  | -0.161         | 0.021   | -9.7%       | -0.279                | 0.029   | -16.0%      | -0.598                | 0.037   | -18.1%      |
| School within ¼ mile   | -0.036         | 0.008   | -2.2%       | 0.242                 | 0.011   | 14.6%       | 0.392                 | 0.015   | 9.6%        |
| Two-Way                | 1.525          | 0.028   | 92.7%       | 1.938                 | 0.047   | 102%        | 1.949                 | 0.072   | 30.0%       |
| # Lanes                | 0.250          | 0.013   | 15.8%       | 0.916                 | 0.016   | 55.0%       | 1.550                 | 0.020   | 26.9%       |
| Counts per Lane        | 0.003          | 3e-05   | 0.2%        | 0.004                 | 4e-05   | 0.2%        | 0.007                 | 6e-05   | -0.9%       |
| Speed Limit            | -0.047         | 0.000   | -2.9%       | -0.112                | 0.001   | -6.6%       | -0.197                | 0.001   | -5.5%       |
| Pop Dens.              | 0.008          | 0.002   | 0.5%        | -0.077                | 0.003   | -4.5%       | -0.176                | 0.005   | -4.9%       |
| Job Dens.              | -0.044         | 0.002   | -2.7%       | -0.037                | 0.003   | -2.2%       | -0.033                | 0.004   | -0.9%       |
| Network Dens.          | -0.023         | 0.002   | -1.4%       | 0.038                 | 0.003   | 2.3%        | 0.134                 | 0.004   | 3.5%        |
| Ped Road Dens.         | -0.081         | 0.002   | -4.9%       | -0.113                | 0.003   | -6.6%       | -0.170                | 0.005   | -4.8%       |
| Intersection Dens.     | 0.009          | 0.000   | 0.5%        | 0.014                 | 0.001   | 0.0%        | 0.015                 | 0.001   | 0.4%        |
| Ped Intersect Dens.    | 0.003          | 0.001   | 0.2%        | -0.031                | 0.001   | -1.8%       | -0.054                | 0.002   | -1.5%       |
| Walk Score             | 0.023          | 0.002   | 1.4%        | 0.005                 | 0.002   | 0.3%        | -0.034                | 0.004   | -0.9%       |
| Pseudo-R <sup>2</sup>  | 0.430          |         |             | 0.601                 |         |             | 0.583                 |         |             |
| Log-Lik                | -1.055e+05     |         |             | -7.147e+04            |         |             | -4.592e+04            |         |             |
| ρ̂                     | 0.623          |         |             | 0.556                 |         |             | 0.477                 |         |             |
| COLLECTORS (N=294,111) |                |         |             |                       |         |             |                       |         |             |
| Constant               | 2.482          | 0.032   |             | 3.445                 | 0.033   |             | 4.328                 | 0.041   |             |
| Night                  | 0.444          | 0.002   | 2.9%        | 0.500                 | 0.003   | 1.2%        | 0.602                 | 0.005   | 0.6%        |
| Light Dens.            | -0.013         | 8e-05   | -0.1%       | -0.012                | 0.000   | -0.0%       | -0.008                | 0.000   | -0.0%       |
| Night x Light          | -0.004         | 0.000   | -0.0%       | -0.009                | 0.000   | -0.0%       | -0.013                | 0.000   | -0.0%       |
| Tuesday                | -0.085         | 0.003   | -0.7%       | -0.068                | 0.000   | -0.3%       | -0.163                | 0.008   | -0.2%       |
| Wednesday              | -0.074         | 0.003   | -0.6%       | -0.096                | 0.005   | -0.3%       | -0.165                | 0.008   | -0.2%       |
| Thursday               | -0.021         | 0.003   | -0.2%       | -0.030                | 0.005   | -0.1%       | -0.132                | 0.008   | -0.2%       |
| Friday                 | -0.086         | 0.003   | -0.7%       | -0.128                | 0.005   | -0.4%       | -0.175                | 0.007   | -0.3%       |
| Saturday               | 0.056          | 0.003   | 0.4%        | 0.059                 | 0.005   | 0.2%        | 0.031                 | 0.007   | 0.0%        |
| Sunday                 | 0.212          | 0.004   | 1.5%        | 0.225                 | 0.005   | 0.6%        | 0.123                 | 0.008   | 0.2%        |
| Urban                  | -1.223         | 0.031   | -15.6%      | -1.475                | 0.031   | -9.4%       | -1.703                | 0.036   | -5.5%       |
| School within ¼ mile   | 0.278          | 0.003   | 1.9%        | 0.358                 | 0.004   | 0.9%        | 0.387                 | 0.006   | 0.4%        |
| Two-Way                | 0.208          | 0.003   | 1.5%        | -0.332                | 0.005   | -1.2%       | -0.567                | 0.009   | -1.0%       |
| # Lanes                | -0.245         | 0.001   | -2.1%       | -0.306                | 0.002   | -1.1%       | -0.227                | 0.004   | -0.3%       |
| Counts per Lane        | 0.004          | 2e-05   | 0.0%        | 0.003                 | 3e-05   | 0.0%        | 0.002                 | 6e-05   | 0.0%        |
| Speed Limit            | -0.038         | 0.000   | -0.3%       | -0.068                | 0.000   | -0.2%       | -0.102                | 0.000   | -0.1%       |

|                                                                                                                                                                                                                                                                                                                                                                                               |            |       |        |            |       |        |            |       |        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-------|--------|------------|-------|--------|------------|-------|--------|
| Pop Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.050     | 0.000 | -0.4%  | -0.054     | 0.000 | -0.2%  | -0.042     | 0.001 | -0.1%  |
| Job Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.012     | 5e-05 | -0.1%  | -0.011     | 8e-05 | -0.0%  | -0.010     | 0.000 | -0.0%  |
| Network Dens.                                                                                                                                                                                                                                                                                                                                                                                 | 0.055      | 0.000 | 0.4%   | 0.059      | 0.000 | 0.2%   | 0.063      | 0.001 | 0.1%   |
| Ped Road Dens.                                                                                                                                                                                                                                                                                                                                                                                | -0.063     | 0.000 | -0.5%  | -0.075     | 0.001 | -0.2%  | -0.094     | 0.001 | -0.1%  |
| Intersection Dens.                                                                                                                                                                                                                                                                                                                                                                            | -0.002     | 4e-05 | -0.0%  | -0.004     | 6e-05 | -0.0%  | -0.004     | 1e-04 | -0.0%  |
| Ped Intersect Dens.                                                                                                                                                                                                                                                                                                                                                                           | -0.001     | 9e-05 | -0.0%  | 0.005      | 0.000 | 0.0%   | 0.012      | 0.000 | 0.0%   |
| Walk Score                                                                                                                                                                                                                                                                                                                                                                                    | -0.058     | 0.000 | -0.5%  | -0.068     | 0.001 | -0.2%  | -0.109     | 0.001 | -0.2%  |
| <i>Pseudo-R<sup>2</sup></i>                                                                                                                                                                                                                                                                                                                                                                   | 0.848      |       |        | 0.613      |       |        | 0.403      |       |        |
| <i>Log-Lik</i>                                                                                                                                                                                                                                                                                                                                                                                | -1.147e+06 |       |        | -6.137e+05 |       |        | -3.115e+05 |       |        |
| $\hat{\rho}$                                                                                                                                                                                                                                                                                                                                                                                  | 0.575      |       |        | 0.525      |       |        | 0.499      |       |        |
| ARTERIALS (N=290,302)                                                                                                                                                                                                                                                                                                                                                                         |            |       |        |            |       |        |            |       |        |
| Constant                                                                                                                                                                                                                                                                                                                                                                                      | -0.651     | 0.019 |        | 1.439      | 0.060 |        | 3.624      | 0.171 |        |
| Night                                                                                                                                                                                                                                                                                                                                                                                         | 0.732      | 0.001 | 51.8%  | 0.810      | 0.002 | 11.9%  | 1.020      | 0.003 | 1.7%   |
| Light Dens.                                                                                                                                                                                                                                                                                                                                                                                   | -0.030     | 5e-05 | -2.0%  | -0.053     | 7e-05 | -1.0%  | -0.068     | 0.000 | -0.2%  |
| Night x Light                                                                                                                                                                                                                                                                                                                                                                                 | 0.002      | 6e-05 | 0.2%   | 0.003      | 8e-05 | 0.1%   | 0.001      | 0.000 | 0.0%   |
| Tuesday                                                                                                                                                                                                                                                                                                                                                                                       | -0.076     | 0.002 | -4.9%  | -0.066     | 0.003 | -1.3%  | -0.133     | 0.005 | -0.4%  |
| Wednesday                                                                                                                                                                                                                                                                                                                                                                                     | -0.100     | 0.002 | -6.5%  | -0.106     | 0.003 | -2.1%  | -0.112     | 0.005 | -0.3%  |
| Thursday                                                                                                                                                                                                                                                                                                                                                                                      | 0.033      | 0.002 | 2.2%   | 0.061      | 0.003 | 1.1%   | 0.037      | 0.005 | 0.1%   |
| Friday                                                                                                                                                                                                                                                                                                                                                                                        | -0.017     | 0.002 | -1.1%  | -0.053     | 0.003 | -1.0%  | -0.204     | 0.005 | -0.6%  |
| Saturday                                                                                                                                                                                                                                                                                                                                                                                      | 0.155      | 0.002 | 10.4%  | 0.143      | 0.003 | 2.6%   | -0.022     | 0.005 | -0.1%  |
| Sunday                                                                                                                                                                                                                                                                                                                                                                                        | 0.308      | 0.002 | 21.1%  | 0.340      | 0.003 | 5.9%   | 0.269      | 0.005 | 0.6%   |
| Urban                                                                                                                                                                                                                                                                                                                                                                                         | 0.437      | 0.018 | 30.3%  | 1.548      | 0.060 | 17.8%  | 3.137      | 0.171 | 2.6%   |
| School within ¼ mile                                                                                                                                                                                                                                                                                                                                                                          | -0.023     | 0.001 | -1.5%  | 0.063      | 0.002 | 1.2%   | 0.155      | 0.004 | 0.4%   |
| Two-Way                                                                                                                                                                                                                                                                                                                                                                                       | -0.399     | 0.003 | -24.4% | -1.768     | 0.004 | -48.2% | -2.988     | 0.007 | -32.9% |
| Median                                                                                                                                                                                                                                                                                                                                                                                        | 0.453      | 0.002 | 31.4%  | 1.514      | 0.003 | 17.6%  | 2.690      | 0.006 | 2.5%   |
| # Lanes                                                                                                                                                                                                                                                                                                                                                                                       | -0.339     | 0.001 | -21.0% | -0.096     | 0.002 | -1.9%  | -0.004     | 0.003 | -0.0%  |
| Counts per Lane                                                                                                                                                                                                                                                                                                                                                                               | 0.001      | 4e-06 | 0.1%   | 0.002      | 6e-06 | 0.0%   | 0.005      | 1e-05 | 0.0%   |
| Speed Limit                                                                                                                                                                                                                                                                                                                                                                                   | -0.004     | 7e-05 | -0.3%  | -0.079     | 1e-04 | -1.5%  | -0.173     | 0.000 | -0.5%  |
| Pop Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.001     | 0.000 | -0.1%  | 0.019      | 0.000 | 0.4%   | -0.003     | 0.000 | -0.0%  |
| Job Dens.                                                                                                                                                                                                                                                                                                                                                                                     | -0.011     | 4e-05 | -0.7%  | -0.020     | 6e-05 | -0.4%  | -0.026     | 9e-05 | -0.1%  |
| Network Dens.                                                                                                                                                                                                                                                                                                                                                                                 | 0.085      | 0.000 | 5.7%   | 0.080      | 0.000 | 1.5%   | 0.100      | 0.000 | 0.3%   |
| Ped Road Dens.                                                                                                                                                                                                                                                                                                                                                                                | -0.146     | 0.000 | -9.3%  | -0.211     | 0.000 | -4.3%  | -0.297     | 0.001 | -0.9%  |
| Intersection Dens.                                                                                                                                                                                                                                                                                                                                                                            | 0.001      | 3e-05 | 0.0%   | 0.004      | 4e-05 | 0.1%   | 0.003      | 7e-05 | 0.0%   |
| Ped Intersect Dens.                                                                                                                                                                                                                                                                                                                                                                           | -0.001     | 5e-05 | -0.1%  | 0.004      | 8e-05 | 0.1%   | 0.015      | 0.000 | 0.0%   |
| Walk Score                                                                                                                                                                                                                                                                                                                                                                                    | 0.005      | 0.000 | 0.3%   | -0.016     | 0.000 | -0.3%  | -0.022     | 0.001 | -0.1%  |
| <i>Pseudo-R<sup>2</sup></i>                                                                                                                                                                                                                                                                                                                                                                   | 1.000      |       |        | 0.999      |       |        | 0.999      |       |        |
| <i>Log-Lik</i>                                                                                                                                                                                                                                                                                                                                                                                | -3.493e+06 |       |        | -1.732e+06 |       |        | -8.573e+05 |       |        |
| $\hat{\rho}$                                                                                                                                                                                                                                                                                                                                                                                  | 0.562      |       |        | 0.562      |       |        | 0.254      |       |        |
| Base: Monday, no access control. Speed data are from INRIX (Nov. 4-10, 2024). Roadway lighting data are from Austin Energy (2026). Road attributes and detailed specifications are from TxDOT’s Roadway Inventory Dataset (2026). School data are from the Texas Education Agency (2025). And land use data for the nearest block group are from the US EPA’s Smart Location Database (2021). |            |       |        |            |       |        |            |       |        |

Overall, roadway lighting was found to be associated with safer nighttime driving behaviors, though effects varied by road class. Nighttime conditions consistently increased speeds and speeding shares across all road types, with the largest increases on arterials. Higher lighting density was linked to significantly lower nighttime speeds on collectors and local roads. In speeding-share models, greater lighting density generally reduced speeding prevalence, particularly for extreme speeding on arterials, but nighttime interaction effects were small or mixed. In summary, lighting is more effective at moderating nighttime speeds, especially extreme speeds, than at reducing speeding shares, with strongest effects on local roads and collectors.

## Intersection and Midblock Crash Model Results

Table 4 presents the NB model results for total intersection crashes, VRU-related intersection crashes, and total midblock crashes over 10 years. Nighttime conditions were associated with fewer crashes at intersections and midblock locations. Relative to daytime conditions, over the past ten years, total intersection crashes were 29.7% lower at night, while VRU intersection crashes were 30.3% lower. This pattern may reflect reduced turning movements, lower traffic volumes, and fewer interaction conflicts after dark. In terms of roadway lighting, for the baseline group, intersections with more light poles tended to have higher crash frequencies, with a one-SD increase in lighting associated with 16.2% higher total crashes and 9.9% higher VRU crashes, suggesting that intersections with higher collision risk may require greater lighting infrastructure. Beyond the baseline relationship, a one-unit increase in lighting density was associated with a 12.9% reduction in nighttime total crashes at intersections and a 13.6% reduction in VRU intersection crashes. These results highlight that additional lighting may be particularly helpful in enhancing VRU safety at intersections. On the other hand, for midblock segments, one more light pole per mile was associated with a modest 0.3% increase in nighttime crashes.

Intersection geometry was also an important factor affecting crash frequency. A one-SD increase in the number of approaches corresponded to 102% higher total intersection crashes and 57.1% higher VRU crashes, indicating that more complex intersections may have higher collision risk. Signalized intersections also experienced higher crash counts, likely reflecting more complex traffic movements, and urban locations had higher crash frequencies as well. Exposure (AADT x length) exhibited the largest effects on midblock crashes, with a one-SD increase associated with a 125% increase in expected crash counts. In addition, built-environment variables also affected crash counts. Higher population density, job density, and walk score were associated with higher crash counts, especially for VRU crashes.

Table 4: Negative Binomial Model Estimates for 10-Yr Crash Counts as a Function of Light Pole Placements (using 2016-2025 CRIS data across City of Austin)

| Variable            | Y = Total 10-yr Intersection Crashes |         |               | Y = 10-yr Intersection VRU Crashes |         |               | Y = Total 10-yr Midblock Crashes |         |               |
|---------------------|--------------------------------------|---------|---------------|------------------------------------|---------|---------------|----------------------------------|---------|---------------|
|                     | Coef.                                | Std Err | Pract. Sign   | Coef.                              | Std Err | Pract. Sign   | Coef.                            | Std Err | Pract. Sign   |
| Constant            | -15.16                               | 0.768   |               | -13.87                             | 1.011   |               | -10.88                           | 0.662   |               |
| Night               | -0.353                               | 0.044   | <b>-16.2%</b> | -0.361                             | 0.077   | -16.5%        | -0.033                           | 0.030   | -1.6%         |
| Light Dens.         | 0.283                                | 0.052   | 16.2%         | 0.177                              | 0.058   | 9.9%          | -0.001                           | 0.001   | -1.6%         |
| Night x Light       | -0.138                               | 0.035   | -5.6%         | -0.146                             | 0.070   | -5.9%         | 0.003                            | 0.001   | 4.2%          |
| # Approaches        | 1.595                                | 0.053   | <b>102%</b>   | 1.027                              | 0.067   | <b>57.1%</b>  | -                                | -       | -             |
| Signalized          | 1.930                                | 0.071   | 38.1%         | 2.161                              | 0.104   | 43.5%         | -                                | -       | -             |
| Urban               | 2.403                                | 0.676   | <b>61.2%</b>  | 1.410                              | 0.915   | 32.3%         | 3.682                            | 0.623   | <b>105%</b>   |
| School within ¼ mi  | 0.132                                | 0.056   | 5.8%          | 0.218                              | 0.075   | 9.8%          | 0.055                            | 0.040   | 2.3%          |
| Log(Major AADT)     | 0.210                                | 0.037   | 50.6%         | 0.185                              | 0.048   | 43.6%         | -                                | -       | -             |
| Log(AADT x len)     | -                                    | -       | -             | -                                  | -       | -             | 0.406                            | 0.020   | <b>125%</b>   |
| Speed Limit [major] | 0.032                                | 0.006   | 32.9%         | 0.001                              | 0.008   | 0.6%          | 0.054                            | 0.003   | 64.1%         |
| Two-way [major]     | 0.448                                | 0.296   | 11.9%         | 0.602                              | 0.211   | 16.4%         | 0.715                            | 0.124   | 18.7%         |
| Arterial [major]    | 0.486                                | 0.171   | 17.1%         | 0.023                              | 0.219   | 0.8%          | -0.390                           | 0.106   | <b>-10.8%</b> |
| Collector [major]   | 0.184                                | 0.117   | 7.3%          | 0.095                              | 0.164   | 3.7%          | -0.403                           | 0.079   | <b>-12.9%</b> |
| # Lanes [major]     | 0.220                                | 0.120   | 12.6%         | 0.176                              | 0.102   | 10.0%         | 0.125                            | 0.055   | 6.2%          |
| Log(Minor AADT)     | 0.070                                | 0.043   | 13.6%         | 0.002                              | 0.049   | 0.3%          | -                                | -       | -             |
| Speed Limit [minor] | 0.008                                | 0.006   | 6.9%          | 0.003                              | 0.008   | 3.0%          | -                                | -       | -             |
| Two-way [minor]     | 0.772                                | 0.277   | 21.0%         | 0.683                              | 0.244   | 18.4%         | -                                | -       | -             |
| Arterial [minor]    | -0.591                               | 0.218   | -15.6%        | 0.189                              | 0.246   | 5.6%          | -                                | -       | -             |
| Collector [minor]   | -0.245                               | 0.156   | -8.3%         | 0.027                              | 0.173   | 0.9%          | -                                | -       | -             |
| # Lanes [minor]     | 0.001                                | 0.122   | 0.0%          | 0.010                              | 0.116   | 0.5%          | -                                | -       | -             |
| Pop Dens.           | 0.025                                | 0.004   | 15.2%         | 0.034                              | 0.004   | 21.3%         | 0.031                            | 0.003   | 18.0%         |
| Job Dens.           | 0.001                                | 0.001   | 2.0%          | 0.010                              | 0.001   | 18.3%         | 0.008                            | 0.001   | 13.5%         |
| Network Dens.       | 0.007                                | 0.009   | 6.6%          | -0.020                             | 0.010   | <b>-16.9%</b> | 0.009                            | 0.005   | 8.7%          |
| Ped Road Dens.      | 0.006                                | 0.009   | 4.6%          | 0.050                              | 0.013   | 43.7%         | 0.008                            | 0.007   | 5.8%          |

|                                                                                                                                                                                                                                                                                                                            |              |       |               |              |       |               |              |       |               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-------|---------------|--------------|-------|---------------|--------------|-------|---------------|
| Intersection Dens.                                                                                                                                                                                                                                                                                                         | 0.001        | 0.001 | 7.7%          | 3e-04        | 0.001 | 2.5%          | -0.001       | 0.001 | -3.5%         |
| Ped Intersect Dens.                                                                                                                                                                                                                                                                                                        | -0.006       | 0.001 | <b>-14.7%</b> | -0.006       | 0.002 | <b>-15.0%</b> | -0.005       | 0.001 | <b>-12.7%</b> |
| Walk Score                                                                                                                                                                                                                                                                                                                 | 0.080        | 0.010 | 41.5%         | 0.115        | 0.015 | <b>65.1%</b>  | 0.112        | 0.008 | 61.9%         |
| $N_{obs}$                                                                                                                                                                                                                                                                                                                  | 72,116       |       |               | 72,116       |       |               | 74,032       |       |               |
| $Pseudo-R^2$                                                                                                                                                                                                                                                                                                               | 0.535        |       |               | 0.091        |       |               | 0.433        |       |               |
| $Log-Lik$                                                                                                                                                                                                                                                                                                                  | $-3.772e+04$ |       |               | $-6.321e+03$ |       |               | $-3.404e+04$ |       |               |
| Sources: Crash data are from CRIS (2016-2025). Roadway lighting data are from Austin Energy (2026). Road attributes are from TxDOT’s Roadway Inventory Dataset (2026). School data are from Texas Education Agency (2025). And land use data for nearest block group are from the US EPA’s Smart Location Database (2021). |              |       |               |              |       |               |              |       |               |

## Difference-in-Differences Model Results

Figure 5 illustrates the distribution of site-level average speed during the before and after period for the 100 non-freeway arterials in the case study. Both the treated and control groups exhibited a slight upward trend in average speed; however, the magnitude of this increase was smaller at the treated sites. Furthermore, both groups demonstrated a negligible change in speed variance across the two periods. These results indicate that while lighting installation may not result in an absolute decrease in travel speeds, it effectively moderates speed growth, maintaining vehicle speeds within a controlled and stable range relative to the broader city-wide increase.

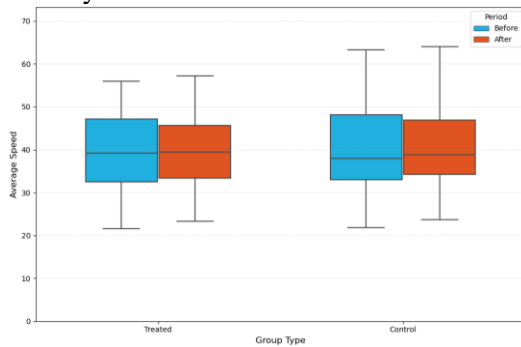


Figure 5. Average Speed Change: Treated vs. Control Across 100 Sites

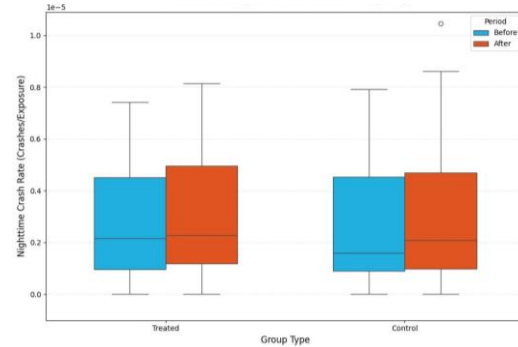


Figure 6. Total Nighttime Crash Rate: Treated vs. Control Across 100 Sites

Table 5 presents the regression model estimates based on 7.1 million segment-level average speed observations. Results indicate that the lighting treatment was associated with increase in vehicle speeds during nighttime periods. Specifically, the early evening period from sunset to 11 p.m. and the late-night period from 11 p.m. to 2 a.m. corresponded to increases in average speed of 0.20 mph and 0.39 mph, respectively. The period from 2 a.m. to sunrise showed a negligible effect of 0.01 mph. However, with p-values ranging from 0.15 to 0.96, these findings suggest that the lighting countermeasure had a limited direct impact on mean speeds in these study areas. In contrast, several infrastructure and land use variables exhibit significant influence on driver behavior. Curb presence was found to be a significant variable, associated with a 4.38 mph decrease in average speeds. Similarly, network density and traffic flow were negatively associated with speed. Among all variables, PSL was the strongest predictor of speeds, with a SD increase in PSL associated with 10.9% higher speeds. Time-of-day effects were substantial, with speeds lowest during morning and evening peak hours (when traffic is heaviest) and highest late at night. Monthly effects indicated slightly slower speeds in February and the spring months, while yearly coefficients suggested gradual increases in speeds over time, with increased speeds observed during the COVID period (2020–2021) and post-period relative to pre-period.

Table 5: Generalized Least Squares Model Estimates for Average Speeds

| Variable         | Coef. | T-stat | P-value | Pract. Sign |
|------------------|-------|--------|---------|-------------|
| Treated x Light1 | 0.201 | 1.4    | 0.154   | 0.2%        |
| Treated x Light2 | 0.390 | 1.4    | 0.161   | 0.2%        |
| Treated x Light3 | 0.007 | 0.0    | 0.963   | 0.01%       |
| Weekend          | 0.960 | 12.6   | 0.000   | 1.1%        |

|                   |           |        |      |       |              |
|-------------------|-----------|--------|------|-------|--------------|
| WMT/sqmi          |           | 0.156  | 0.2  | 0.837 | 0.4%         |
| % one-car HH      |           | 2.626  | 0.4  | 0.724 | 0.7%         |
| % 2+ car HH       |           | -2.694 | -0.3 | 0.749 | -0.9%        |
| Walk Score        |           | -0.253 | -0.9 | 0.346 | -2.6%        |
| Job Dens.         |           | 0.296  | 0.9  | 0.362 | 2.1%         |
| Network Dens.     |           | -0.261 | -1.6 | 0.104 | <b>-5.0%</b> |
| Air Tem           |           | 0.017  | 2.2  | 0.029 | 0.7%         |
| # Lanes           |           | -0.399 | -0.4 | 0.678 | -0.8%        |
| Raised Pres       |           | 2.695  | 2.3  | 0.020 | 3.4%         |
| Depressed Pres    |           | 2.628  | 1.8  | 0.077 | 1.6%         |
| Bike lane Pres    |           | 1.385  | 0.7  | 0.455 | 0.7%         |
| Sidewalk Pres     |           | -1.333 | -0.8 | 0.400 | -1.7%        |
| Sidewalk x buffer |           | 0.831  | 0.4  | 0.690 | 0.9%         |
| Flow/lane         |           | -0.007 | -7.5 | 0.000 | <b>-3.1%</b> |
| On-street Parking |           | 2.170  | 0.6  | 0.521 | 1.0%         |
| Curb Pres         |           | -4.382 | -2.5 | 0.013 | <b>-5.5%</b> |
| Tangent Pres      |           | 1.186  | 1.0  | 0.341 | 1.5%         |
| Speed Limit       |           | 0.699  | 4.1  | 0.000 | <b>10.9%</b> |
| Hour of the day   |           |        |      |       |              |
|                   | 1         | -0.584 | -6.5 | 0.000 |              |
|                   | 2         | -0.744 | -5.0 | 0.000 |              |
|                   | 3         | -0.698 | -4.0 | 0.000 |              |
|                   | 4         | -0.598 | -3.0 | 0.003 |              |
|                   | 5         | -0.710 | -2.7 | 0.007 |              |
|                   | 6         | -1.462 | -4.8 | 0.000 |              |
|                   | 7         | -3.081 | -7.6 | 0.000 |              |
|                   | 8         | -3.060 | -6.4 | 0.000 |              |
|                   | 9         | -2.934 | -5.8 | 0.000 |              |
|                   | 10        | -3.117 | -5.9 | 0.000 |              |
|                   | 11        | -3.166 | -6.0 | 0.000 |              |
|                   | 12        | -2.879 | -5.4 | 0.000 |              |
|                   | 13        | -2.303 | -4.7 | 0.000 |              |
|                   | 14        | -2.511 | -5.1 | 0.000 |              |
|                   | 15        | -2.907 | -6.1 | 0.000 |              |
|                   | 16        | -2.635 | -5.0 | 0.000 |              |
|                   | 17        | -2.437 | -4.4 | 0.000 |              |
|                   | 18        | -1.600 | -3.4 | 0.000 |              |
|                   | 19        | -0.950 | -2.6 | 0.009 |              |
|                   | 20        | -0.507 | -1.9 | 0.055 |              |
|                   | 21        | -0.071 | -0.4 | 0.716 |              |
|                   | 22        | 0.423  | 3.0  | 0.003 |              |
|                   | 23        | 0.586  | 5.4  | 0.000 |              |
| Month of Year     |           |        |      |       |              |
|                   | February  | -0.479 | -9.5 | 0.000 |              |
|                   | March     | -0.360 | -3.0 | 0.003 |              |
|                   | April     | -0.320 | -1.8 | 0.070 |              |
|                   | May       | -0.420 | -1.7 | 0.088 |              |
|                   | June      | -0.375 | -1.3 | 0.196 |              |
|                   | July      | -0.278 | -0.9 | 0.383 |              |
|                   | August    | -0.401 | -1.3 | 0.196 |              |
|                   | September | -0.319 | -1.2 | 0.235 |              |
|                   | October   | -0.212 | -1.1 | 0.277 |              |
|                   | November  | 0.004  | 0.0  | 0.968 |              |

|                                                                                                                                                                                                                 |           |        |     |       |  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|--------|-----|-------|--|
|                                                                                                                                                                                                                 | December  | 0.167  | 2.7 | 0.008 |  |
| Year                                                                                                                                                                                                            |           |        |     |       |  |
|                                                                                                                                                                                                                 | 2018      | 13.228 | 1.4 | 0.164 |  |
|                                                                                                                                                                                                                 | 2019      | 13.766 | 1.4 | 0.148 |  |
|                                                                                                                                                                                                                 | 2020      | 15.078 | 1.6 | 0.112 |  |
|                                                                                                                                                                                                                 | 2021      | 15.708 | 1.7 | 0.098 |  |
|                                                                                                                                                                                                                 | 2022      | 15.548 | 1.6 | 0.102 |  |
|                                                                                                                                                                                                                 | 2023      | 15.072 | 1.6 | 0.113 |  |
|                                                                                                                                                                                                                 | 2024      | 14.603 | 1.5 | 0.124 |  |
|                                                                                                                                                                                                                 | 2025      | 14.552 | 1.5 | 0.125 |  |
| $N_{site}$                                                                                                                                                                                                      | 100       |        |     |       |  |
| $N_{obs}$                                                                                                                                                                                                       | 7,070,077 |        |     |       |  |
| $R^2$                                                                                                                                                                                                           | 0.615     |        |     |       |  |
| Log-likelihood                                                                                                                                                                                                  | -2.1e+07  |        |     |       |  |
| Note: In Random Effects model, the first category of categorical variables (year=2018, month=Monday, hour=1) is the baseline and is absorbed by entity-level random effects, so no separate intercept is shown. |           |        |     |       |  |

Figure 6 compares nighttime crash rates between 47 treated (receive lighting) and 53 control (unlighted both before and after) arterial segments (with a total length of 92.62 centerline-miles). While both groups experienced an increase in crash rates (per VMT), the increase at treated sites was notably smaller than that observed in the control group. Table 6 present the total and VRU-related nighttime crash model results for the lighting treatments based on 100 Texas arterial-roadway segments (where 27,263 crashes were reported over 7 years). Results indicate that the treated (with lighting) arterials in Texas were associated with 24.4% fewer intersection-related nighttime crashes, but 53.1% more VRU-related crashes (perhaps due to more pedestrians and cyclists being attracted to the corridor). However, neither estimate is statistically significant (p-values = 0.531 and 0.449), suggesting that the observed changes may be attributable to random fluctuation or site-level variance rather than the lighting treatment. Among roadway covariates, VMT and WMT density were the most significant variables affecting crashes, both showing strong positive correlations with crashes. Besides, the presence of a separate bike lane was associated with a reduction in nighttime crashes.

Table 6. Generalized Linear Mixed Model Estimates for Crash Counts

| Variable               | Total Nighttime Crashes |        |           | VRU Nighttime Crashes |        |           | Intersection Nighttime Crashes |        |           |
|------------------------|-------------------------|--------|-----------|-----------------------|--------|-----------|--------------------------------|--------|-----------|
|                        | Coef.                   | T-stat | P-value   | Coef.                 | T-stat | P-value   | Coef.                          | T-stat | P-value   |
| Intercept              | -321.2                  | -6.1   | 0.000     | -5.647                | -1.6   | 0.104     | -109.8                         | -4.8   | 0.001     |
| Treated x After        | 5.511                   | 0.6    | 0.531     | 0.426                 | 0.8    | 0.449     | -0.280                         | -0.1   | 0.942     |
| Treated                | 15.986                  | 2.5    | 0.014     | 0.407                 | 1.0    | 0.316     | 7.279                          | 2.6    | 0.010     |
| After                  | 6.275                   | 1.1    | 0.281     | 0.093                 | 0.3    | 0.802     | 2.785                          | 1.1    | 0.271     |
| WMT/sqmi               | 14.73                   | 3.7    | 0.000     | 0.610                 | 3.4    | 0.001     | 5.558                          | 3.4    | 0.001     |
| Walk Score             | 2.280                   | 1.9    | 0.055     | -0.012                | -0.2   | 0.842     | 0.885                          | 1.8    | 0.072     |
| Lane Width             | -4.445                  | -1.5   | 0.125     | -0.212                | -1.3   | 0.190     | -1.886                         | -1.5   | 0.122     |
| Depressed Pres         | 20.16                   | 1.5    | 0.133     | 0.292                 | 0.4    | 0.663     | 8.675                          | 1.5    | 0.125     |
| Bike Lane Pres         | -31.91                  | -1.6   | 0.097     | -1.488                | -1.5   | 0.131     | -9.770                         | -1.2   | 0.215     |
| Sidewalk Pres          | -17.63                  | -2.0   | 0.045     | 0.864                 | 2.0    | 0.051     | 2.394                          | 0.7    | 0.500     |
| Ln(AADT                | 22.73                   | 9.8    | 0.000     | 0.486                 | 2.9    | 0.004     | 7.656                          | 7.8    | 0.000     |
| Tangent Pres.          | 10.62                   | 1.8    | 0.073     | 0.799                 | 2.4    | 0.018     | 5.939                          | 2.4    | 0.018     |
| Random Effects         |                         |        |           |                       |        |           |                                |        |           |
| Group Variable         | Variance                |        | Std. Dev. | Variance              |        | Std. Dev. | Variance                       |        | Std. Dev. |
| Site Name              | 780.3                   |        | 9.091     | 0.479                 |        | 0.369     | 100.8                          |        | 3.241     |
| <i>N<sub>obs</sub></i> | 193                     |        |           | 193                   |        |           | 193                            |        |           |
| <i>Log-likelihood</i>  | -928.5                  |        |           | -410.1                |        |           | -772.3                         |        |           |

## CONCLUSIONS

1 This study examines the speed and safety impacts of roadway lighting using different data sets and model  
2 specifications. A series of analyses combine one month of INRIX probe vehicle data, roadway lighting  
3 inventories, police-reported crash records, roadway characteristics, traffic exposure measures, and  
4 corresponding land-use variables to examine how lighting affects nighttime driver behavior and crash  
5 outcomes across 100 Texas arterial corridors and thousands of City of Austin roadway links, with and  
6 without roadway illumination (via lighting poles).

7 Cross-sectional models for vehicle speeds in Austin show that nighttime conditions are associated with  
8 higher speeds across all road classes. Corridors with higher lighting density have lower nighttime speeds  
9 (*ceteris paribus* - after controlling for roadway design details, AADT, local land use and network factors).  
10 Each additional light pole per mile is associated with 0.04 mph lower mean speeds on locals and collectors  
11 (suggesting that lighting is more effective at reducing nighttime speeds on lower-class roadways).  
12 Speeding-share models indicate that the effect of additional light poles (lighting density) on speeding shares  
13 is small (after some base level of illumination is provided) on higher-class roads. On local roads, relative  
14 to the baseline daytime lighting effect, one additional light pole per mile was associated with a 1.6%  
15 decrease in nighttime speeding percentage.

16 Crash-count model results suggest that added intersection lighting lowers nighttime crash rates (for all  
17 travelers) while delivering significant crash-reduction benefits for pedestrians and cyclists. For example, a  
18 single added light pole per intersection is estimated to deliver 12.9% lower nighttime crash counts at that  
19 location and 13.6% lower nighttime VRU crash counts (beyond the baseline effect of having illumination  
20 at that intersection). In the DiD analysis using 100 non-freeway arterials in Texas, lighting-treated corridors  
21 (which had somewhat higher crash rates to begin with, which may be why lighting was added to them)  
22 experienced lower crash-rate increases than control corridors over the 7-year period, and an estimated  
23 24.4% reduction in nighttime intersection crashes after lighting installation (although treatment effects were  
24 not statistically significant in this small dataset, with 8 control variables). Lighting-added corridors also  
25 showed smaller increases in operating speeds than control sites, suggesting that lighting may help limit  
26 speed growth over time.

27 Future work on the benefits of roadway (and intersection) illumination should try to estimate illumination  
28 levels (in lumens, for example) per square foot of roadway and adjacent sidewalks (for example), instead  
29 of relying on pole density. Such computations can reflect lamp wattage, mounting height, spacing,  
30 shielding, pavement reflectivity, maintenance conditions, and tree-canopy blockage, to better infer actual  
31 illuminance. In addition, larger samples for DiD analysis, longer after-period observations, longer-duration  
32 speed samples (involving more household vehicles, rather than INRIX's commercial-vehicle-biased  
33 sample), and more detailed site-treatment histories may enable better estimates of the speed and safety  
34 impacts of roadway lighting.

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