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MARYLAND DEPARTMENT OF TRANSPORTATION
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RESEARCH REPORT

MD 210 BEFORE AND AFTER CASE STUDY FOR SPEED MANAGEMENT PRACTICES

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16. Abstract

MD 210 is known as one of the most dangerous roads in the state of Maryland. While MDOT SHA is aware that speeding is contributing factor in most crashes on MD 210, conventional efforts to reduce speeding, such as signing and automated speed enforcement have not been successful. In addition to speeding, driving behaviors such as harsh braking, harsh accelerations, and distracted driving can further increase the risk of crashes, especially when paired with excessive speeding. To more fully capture and address safety issues on MD 210, it is important to understand a broader range of unsafe driving behaviors beyond speeding alone. To address this urgent need, the CATT Lab employed a multi-faceted approach to the MD 210 safety issue, using both traditional and non-traditional traffic safety data to explore factors contributing to MD 210 safety issues and to evaluate the effectiveness of planned engineering solutions. Non-traditional traffic safety data included telematics-style data from Michelin that summarized harsh driving events on roadway segments. The study developed a rigorous analysis framework that included the use of Gower distance for control site selection, and the application of Interrupted Time Series and Difference-in-Differences models to evaluate the change in key safety performance measures. The study found that the installed countermeasures did not significantly impact the safety performance of MD 210.

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Introduction

Despite the tremendous effort of transportation safety professionals, over-speeding remains a significant challenge. In the U.S., the National Highway Traffic Safety Administration (NHTSA) reported that speeding-related fatalities increased by 8% between 2020 and 2021 and that speeding was involved in 29% of fatal crashes (*1*). To combat this trend, traffic safety decision makers employ various over-speeding countermeasures to reduce the frequency and severity of motor vehicle crashes. The impact of a given countermeasure is then evaluated by comparing safety performance measures between the before and after periods.

In the state of Maryland, MD 210 in Prince George's County is known as one of the most dangerous roads in the state. While several countermeasures have been installed in recent years, MD 210 continues to experience a serious safety performance issue. For the years 2015 – 2022, MD 210 experienced 3,433 crashes resulting in 8,707 injuries (*2*). These statistics suggest that there were approximately 1.2 reported crashes with 3.0 persons injured each day on MD 210 during this period. Figure 1 presents the annual crash trends by injury severity on MD 210 from 2015-2022. While there was a decreasing trend in injuries from crashes on MD 210 in the years 2017-2019, the trend increased in 2021 and 2022. These findings suggest that further safety improvements are needed to ensure reduced crash risk on MD 210.

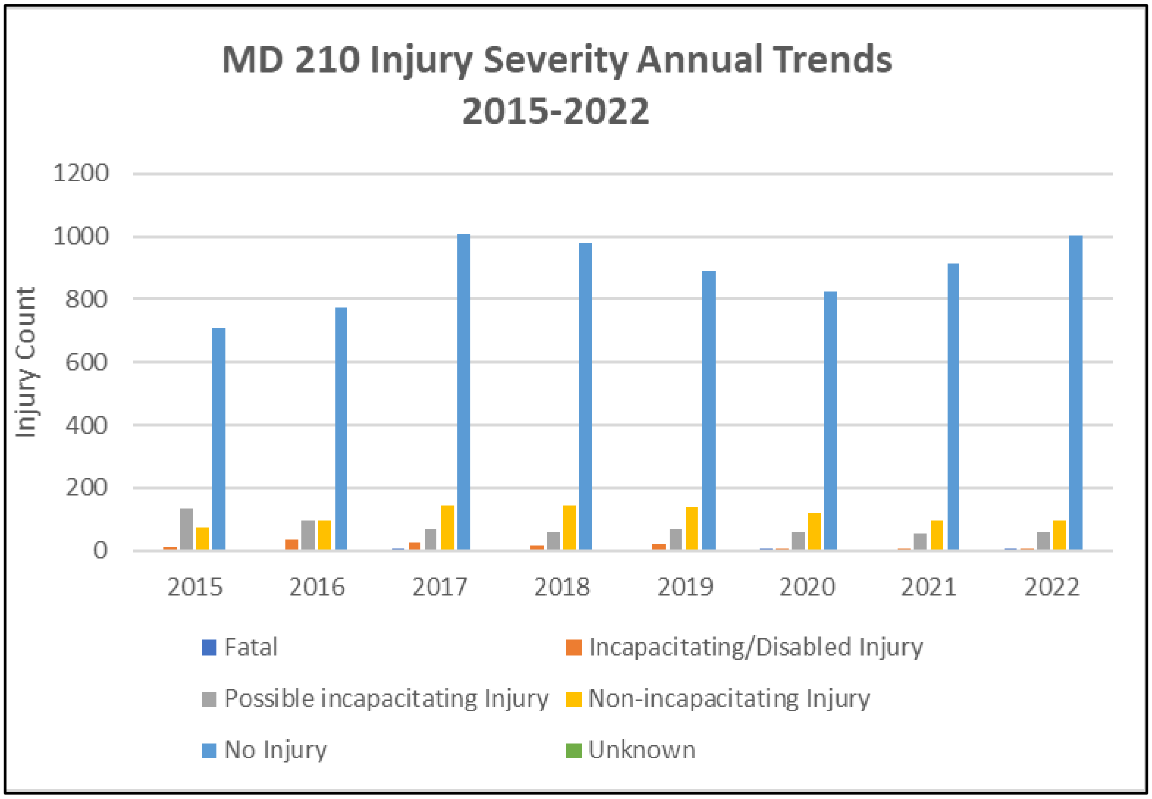


Figure 1 MD 210 Injury and Non-Injury Crash Trends (2015-2022)

Recognizing that a significant portion of crashes on MD 210 involved over-speeding as a contributing factor, the Maryland Department of Transportation (MDOT) has explored several countermeasures such as automated speed enforcement, high-visibility enforcement, and outreach. However, the speeding safety issue remained on MD 210. To address the persistent safety concerns with limited resources for countermeasure installation, MDOT safety engineers began to explore non-traditional speeding countermeasures including narrowing on lanes from 12 feet to 11 feet and quick-curbs with flex-posts and panels on both shoulders. Figure 2 shows the location of countermeasure installations on MD 210.

Figure 2 Map of safety countermeasure installation on MD 210

In this research, a data-driven framework was developed to evaluate the effectiveness of the installed countermeasures on MD 210. To achieve this, the research team utilized data from multiple sources. First, probe vehicle speed data was provided by INRIX and accessed through the University of Maryland's Center for Advanced Transportation Technology Laboratory's (UMD-CATT Lab) Regional Integrated Transportation Information System (RITIS). In addition, the team leveraged the Maryland State Police Crash database, the Automated Crash Reporting System (ACRS), to investigate the historical crash patterns. Lastly, the team partnered with Michelin Mobility Solutions and Arity to evaluate event data derived from smartphone apps. This dataset provides valuable insights on safety related events including harsh braking, harsh acceleration, and excessive speeding from individual vehicles. In addition, Michelin-Arity provides origin-destination data for trips that use a specified collection of segments.

The safety evaluation framework includes an advanced control site selection method based on the Gower distance. A rigorous methodology to compare safety performance measures before and after countermeasure installation was developed using the Difference-in-Differences (DiD) and Interrupted Time Series (ITS) statistical methods. The research team applied this framework to assess the impact of safety countermeasures on MD 210.

Literature Review

There has been extensive research on before and after evaluations of traffic safety countermeasures. This literature review aims to summarize recent studies on safety countermeasure installations with an emphasis on countermeasures to address excessive speeding. Though the countermeasures for this study were pre-determined, the results of this literature review may inform future safety improvements on MD 210.

Countermeasure Selection and Analysis

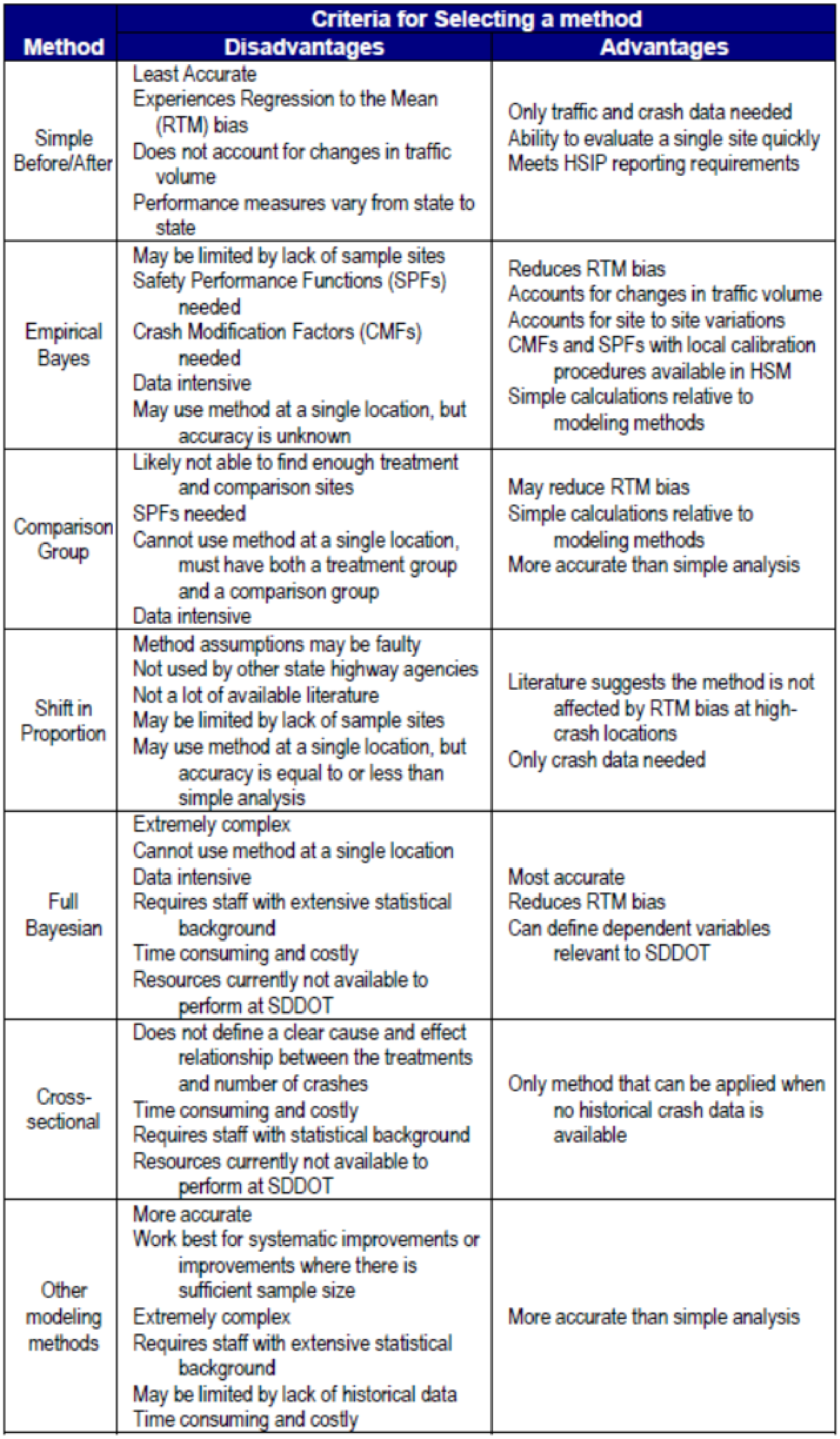
The groundbreaking publication of the first edition of the Highway Safety Manual (HSM) (*3*) provides a framework for planning and evaluating highway safety improvements. The HSM is supplemented by the Federal Highway Administration's (FHWA) Crash Modification Factor (CMF) Clearinghouse which provides details on the historical and expected performance of safety improvements/countermeasures (*4*). These resources are used to determine the most appropriate countermeasure(s) for a given target site.

Once the final countermeasure(s) are selected and installed, before-after studies are often conducted to assess the effectiveness of the countermeasure(s) in improving roadway safety. The recent study by the South Dakota Department of Transportation provides an overview of the common techniques used to conduct a before and after study to evaluate the effectiveness of the employed countermeasures (*5*). Table 1 provides a modified summary of the advantages and disadvantages of various before and after methods from the work of Steever (*5*).

Before and after safety studies often face the challenge of confounding bias, where variables related to both the intervention and the outcome can skew results. Appropriate statistical analyses can adjust for confounders that are known and accurately recorded. However, some confounding factors may be unknown, or known but not recorded or inaccurately recorded. Given that before and after study periods are usually completely separated in time, distinguishing the effect of the intervention from the effect of time on the outcome is a primary challenge. One potential confounding factor in such studies is traffic volume which generally increases over time, leading to a higher number of speeding or braking events in later periods. Another issue is regression to the mean, where safety interventions are often introduced in response to a perceived problem, and a high-incidence period is naturally followed by a low-incidence period as the incidence returns to its long-term average. This regression to the mean occurs independently of any intervention due to random variation, potentially giving the false impression of an intervention's effectiveness.

To account for these issues, the Empirical Bayes (EB) procedure was introduced by Hauer in 1997 for conducting observational before and after studies (*6*). This method has since become a widely used method for evaluating the effectiveness of safety countermeasures (*7-10*). The EB approach measures the change in safety by comparing the expected number of crashes, which would have occurred in the absence of treatment, to the actual number of crashes reported after the treatment. This expected number is calculated using a Safety Performance Function (SPF), a mathematical model that predicts crash occurrences based on site characteristics. However, when countermeasures are effective only for a short duration, SPFs may yield biased results due to the typically low number of crashes during the brief after period. EB also requires many reference groups with similar characteristics, where similarity is not rigorously defined in a consistent manner (*11*).

Table 1. Summary of Before-After Analysis Methods (*5*)



Method	Criteria for Selecting a method	
	Disadvantages	**Advantages**
Simple Before/After	Least Accurate Experiences Regression to the Mean (RTM) bias Does not account for changes in traffic volume Performance measures vary from state to state	Only traffic and crash data needed Ability to evaluate a single site quickly Meets HSIP reporting requirements
Empirical Bayes	May be limited by lack of sample sites Safety Performance Functions (SPFs) needed Crash Modification Factors (CMFs) needed Data intensive May use method at a single location, but accuracy is unknown	Reduces RTM bias Accounts for changes in traffic volume Accounts for site to site variations CMFs and SPFs with local calibration procedures available in HSM Simple calculations relative to modeling methods
Comparison Group	Likely not able to find enough treatment and comparison sites SPFs needed Cannot use method at a single location, must have both a treatment group and a comparison group Data intensive	May reduce RTM bias Simple calculations relative to modeling methods More accurate than simple analysis
Shift in Proportion	Method assumptions may be faulty Not used by other state highway agencies Not a lot of available literature May be limited by lack of sample sites May use method at a single location, but accuracy is equal to or less than simple analysis	Literature suggests the method is not affected by RTM bias at high-crash locations Only crash data needed
Full Bayesian	Extremely complex Cannot use method at a single location Data intensive Requires staff with extensive statistical background Time consuming and costly Resources currently not available to perform at SDDOT	Most accurate Reduces RTM bias Can define dependent variables relevant to SDDOT
Cross-sectional	Does not define a clear cause and effect relationship between the treatments and number of crashes Time consuming and costly Requires staff with statistical background Resources currently not available to perform at SDDOT	Only method that can be applied when no historical crash data is available
Other modeling methods	More accurate Work best for systematic improvements or improvements where there is sufficient sample size Extremely complex Requires staff with extensive statistical background May be limited by lack of historical data Time consuming and costly	More accurate than simple analysis

Econometrics literature has developed two classes of methods, Interrupted Time Series (ITS) and Difference-in-Differences (DiD), that are well suited to before-after studies and handle exogenous effects over time. DiD and ITS have become prominent in transportation research for evaluating the impact of policy changes, infrastructure improvements, and interventions on traffic safety outcomes. DiD, initially developed in economics to assess the effectiveness of training on earnings (*12*), adjusts a naïve measurement of the before and after period difference by controlling any changes observed in an untreated group with otherwise similar attributes. In the transportation safety literature, DiD has been used to measure the impact of a wide variety of road safety interventions on crash counts or rates. The interventions studied have included driver licensing programs, texting bans, infrastructural modifications such as rumble strips or pavement resurfacing, seat belt laws, congestion charge zones, and speed limit changes (*10, 11, 13-18*).

The ITS class of methods were introduced by Box and Tiao in 1975 (*19*) to handle economic and environmental research questions where the impact of a sudden intervention might manifest in time series data. These methods have also proven effective in assessing the impact of policy changes or infrastructure improvements on crash counts and rates. For example, this analytical approach has been utilized to evaluate the efficacy of policy changes related to road safety measures, such as speed limit changes (*20, 22*), increased traffic fines (*23*), COVID lockdowns (*20–22*), and infrastructure improvements—such as the implementation of transit signal priority (*27*).

DiD and ITS offer an analytical approach in assessing the effects of policy changes and interventions on traffic safety outcomes. Both methods have demonstrated their effectiveness in isolating the impact of specific interventions or policies on outcomes of road safety. In contrast to EB, DiD and ITS do not necessarily require a large number of reference groups with similar characteristics to the treated group. Selection of reference groups is more rigorously defined for both DiD and a controlled version of ITS: measurements of the dependent variables of both groups must follow a parallel trend before the intervention or treatment (*11*).

Speeding Countermeasures

The countermeasures are presented in the general categories of engineering, technology, enforcement, education and outreach, and planning and policy.

Engineering

There is a wide and extensive body of literature on engineering countermeasures for speed management, covering various aspects of road design, traffic control devices, and their impact on driver behavior and speed reduction. This section provides a brief overview and summary of some of the most cited publications in this area.

According to the most recent version of National Highway Traffic Safety Administration (NHTSA) Safety Countermeasure Guide (*28*), engineering measures for speed management include traffic calming designs like roadway diets, which utilize devices, markings, and structures to slow down traffic and enhance safety near schools, parks, and other areas. A similar concept is self-enforcing roadways, where geometric features and visual cues are employed to encourage drivers to intuitively adopt appropriate speeds without relying solely on posted speed

limit signs (*29*). These measures, when carefully implemented, can improve traffic flow, reduce crashes, and effectively manage speeds in various contexts.
Wotring et al. (*30*) conducted a comprehensive literature review on countermeasures for speed management. They categorized engineering countermeasures based on their application in Roadway Crashes (Table 2) and Intersection Crashes and Pedestrian Conflicts (Table 3), providing valuable insights into effective strategies for mitigating crash risks and enhancing safety.

Table 2. Engineering Solutions for Roadway Crashes (*30*)

Signage	Roadway design
• Advanced notice speed signs • Advanced warning flashers • Advanced warning signs • Advisory speed signs • Chevrons • Dynamic curve warnings • Enhanced curve delineation • Flashing beacons • Fluorescent sign coatings • Gateway treatments • Horizontal deflection • In-roadway warning lights • Pavement marking legends • Rectangular rapid flash beacons • Repeater signs • Speed advisory signs • Speed feedback signs • Speed limits • Speed limits at high-risk areas • Valid speed limits • Variable message signs • Work zone speed limits	• Add right side bike lanes • Architectural treatments • Change vertical grade • Chicanes • Consistent roadway geometry • Improve sight distance • Improve superelevation • Increased pavement friction in target areas • Lateral shift • Minor road/road splitter island • Modify horizontal curve radius • Neck-down • Paved shoulder • Profile thermoplastic markings • Reduce nonrecurring delays • Reflective barrier delineation • Road diet • Roadside object delineation • Rumble strips/stripes • Safety edge – easier return to pavement by eliminating drop off • Self-enforcing roadway design • Skid resistant surface treatment • Transverse rumble strips • Tubular channelizers • Vertical treatments • Walkways and shoulders • Widen edge lines

Table 3. Engineering Solutions for Intersection Crashes and Pedestrian Conflicts (*30*)

Signage	Roadway design
• Advanced notice speed signs • Advanced warning flashers • Advanced warning signs	• Add or remove street parking • Add right side bike lanes • Architectural treatments

Signage	Roadway design
• Advisory speed signs • Flashing beacons • Fluorescent coatings • In-roadway pedestrian crossing signs • In-roadway warning lights • Increased pavement friction in target areas • Install or upgrade pedestrian signals • Pavement marking legends • Protected-only signal phases • Speed advisory signs • Speed feedback signs • Speed limits • Speed limits at high-risk areas • Speed safety zones • Variable message signs • Valid speed limits	• Chicanes • Chocker/bulb-out • Closure/diversions • Curb extension • Diagonal diverter • Median island • Mini roundabout • Neck-down • Raised pavement markers • Reduce lane width on intersection • approaches • Refugee islands • Roundabouts • Skid resistant surface treatment • Speed bumps
Markings	Roadside treatments
• Lane narrowing with pavement markings • Pavement speed limit marking • Optical speed bars with and without decreasing spacing • Realigned intersection • Repaint crosswalks • Zig zags	• Change or mitigate the effects of identified elements in the environment • Enhanced lighting/visibility • Landscaping • Implement sight changes or improvements • Trim trees to increase visibility

In a study by Distefano and Leonardi (*31*), the impact of chicanes, speed tables, and road narrowing on speed reduction was examined. The results showed that chicanes and speed tables resulted in a 50% reduction in speed, while road narrowing achieved a 35% decrease. In their study, Rahman et al. (*32*) used microsimulation to investigate the impact of a two-step speed reduction, driveway reduction, and replacing a two-way left turn lane (TWLTL) with a raised median in school zones. The results indicated that both two-step speed reduction and driveway reduction, as well as their combination, effectively reduced crash risks. However, replacing TWLTL with a raised median was found to increase crash risk. Arvidson (*33*) conducted a study on roundabouts in Minnesota and found that changing intersection signing and striping resulted in a significant 50% reduction in both improper turns and drivers choosing the incorrect lane. Additionally, narrowing the roadway down to 10 feet led to a reduction in speed of 3 mph for each foot, and introducing curbs on road segments longer than 200 feet with a speed limit of 45 mph or higher resulted in a reduction in speed of 1.2 mph.

Technology

Intelligent Transportation Systems (ITS) technologies have gained significant attention from transportation agencies as valuable tools for developing effective traffic safety countermeasures. While conventional engineering approaches have proven effective in reducing crashes, their efficacy may be limited under specific circumstances. ITS-based countermeasures offer enhanced capabilities for speed management on roadways. This section provides a comprehensive overview of case examples that highlight the application of ITS-related countermeasures in speed management and crash reduction, emphasizing their effectiveness and potential to enhance overall traffic safety.

The Proven Safety Countermeasures Initiative (PSCi) by the Federal Highway Administration (FHWA) encompasses a compilation of 28 countermeasures and strategies that have demonstrated effectiveness in significantly reducing fatalities and severe injuries on the nation's highways (*34*). Speed Safety Cameras are listed in PSCi as a countermeasure for speed management. A study conducted in Scottsdale, Arizona (*35*) examined the impact of a fixed-camera photo speed enforcement program (SEP) on speeding behavior, crashes, and economic costs. The program, implemented on a 6.5-mile urban freeway segment from January to October 2006, resulted in a significant increase in speeding detection frequencies and a reduction in average speeds within the enforcement zone. The program was found to decrease various crash types, except for rear-end crashes, and was estimated to provide approximately $17 million in annual safety benefits based on Arizona-specific crash-related injury costs.

Another ITS-based safety countermeasure listed in PSCi for speed management is Variable Speed Limits (VSLs). By utilizing real-time data on traffic speed, volumes, weather, and road surface conditions, VSLs dynamically determine suitable speeds and communicate those speeds to drivers. The implementation of VSLs holds the potential to effectively reduce both the frequency and severity of crashes. Pu et al. (*9*) conducted a study to evaluate the safety impacts of a VSL system implemented on Interstate 5 in Seattle, Washington since 2010. Using a Full Bayesian before-after analysis based on 9,787 crashes over a 72-month period, the study found that the VSL system resulted in a 32.23% reduction in the total crash count. The reduction was most significant for rear-end crashes and least significant for sideswipe crashes. Additionally, the study compared traffic speed before and after the implementation of VSL and found a decrease in speed differences (i.e., increased speed harmonization) with the system in place.

In addition to Speed Safety Cameras and VSLs, several other ITS-based safety countermeasures have proven effective in enhancing speed management and overall traffic safety. Wu (*36*) investigated the effectiveness of Driver Feedback Signs (DFSs) in reducing collisions by conducting a before-after empirical Bayes analysis in the City of Edmonton, Alberta, Canada. The findings showed significant collision reductions, particularly for severe speed-related collisions, and demonstrated that DFSs can be an economical and strategic countermeasure for improving road safety. Avelar et al. (*37*) evaluated the effectiveness of adaptive signal control technologies (ASCTs) as a safety improvement strategy on multilane arterials in urban corridors using safety data from Florida, Texas, and Virginia. The results showed statistically significant crash reductions in Virginia, a significant reduction in rear-end crashes in Texas, and no significant changes in safety in Florida. In another study, Hallmark et al. (*38*) evaluated the effectiveness of dynamic speed feedback signs in reducing speed and crashes on curves of rural two-lane roadways. The results showed significant decreases in mean speeds and reductions in the number of vehicles exceeding speed limits. Tribbett et al. (*39*) conducted a study on five dynamic curve warning systems installed by CALTRANS in the Sacramento River Canyon. The systems, consisting of Changeable Message Signs (CMS) coupled with radar measurement, showed preliminary results of reductions in accidents and operating speeds, positive motorist acceptance, and minimal maintenance difficulties.

Enforcement

Ensuring speed compliance is crucial for promoting road safety and reducing the occurrence of crashes. To achieve this goal, a series of countermeasures have been developed, as listed by Wotring et al. (*30*) in a comprehensive literature review. These countermeasures encompass a range of strategies that aim to influence driver behavior and encourage adherence to speed limits. The countermeasures are listed in Table 4.

Table 4. Enforcement Countermeasures (*30*)

- Adjust enforcement thresholds
- Aggressive driving laws
- Bumper stickers for speed infraction identification
- Cite both drivers, passengers, and pedestrians
- Decoy officers
- Differential speed limits by vehicle class
- High visibility enforcement
- Increase the perception of being caught
- Intra-country or intra-state enforcement
- Licensing and speed restrictions
- Multiple enforcement activities over time
- Phased enforcement
- Saturation patrol
- Set speeds by road use
- Slower speed zones
- Systematic reduction in speed zones
- Targeted enforcement

Automated speed enforcement (ASE) systems are commonly deployed in many countries to address the risk of speeding-related injuries. A study conducted by Beaton et al. reveals that the majority of British Columbians show acceptance and support for the use of automated speed enforcement (ASE) technologies in B.C., suggesting the need for strategies to foster public buy-in and ensure successful implementation and expansion of ASE programs (*40*). Aldossari and Bandara (*41*) conducted a study that provides compelling evidence demonstrating that ASE is the most effective tool in mitigating and reducing various types of crashes globally. However, driver awareness of enforcement locations led to avoidance behavior, undermining the effectiveness of ASE and potentially increasing crash risk due to abrupt speed changes near enforcement zones. To overcome this issue, section speed enforcement systems (SSES) were developed to enforce speed limits based on average travel speed over a specific section. A study evaluating SSES implementation on Korean expressways found that vehicles reduced their speeds within enforcement sections, leading to decreased speed variations and lower crash risks (*8*). The analysis estimated a 43% reduction in crash occurrence after SSES installation, with an immediate impact observed.

Education and Outreach

Educational campaigns and outreach initiatives hold significant potential in addressing the issue of speeding in traffic. By targeting driver behavior and fostering a culture of responsible driving, these interventions contribute to improved road safety outcomes. Additionally, effective communication and outreach initiatives are crucial components of successful enforcement programs (*42*). Wotring et al. (*30*), listed education and outreach countermeasures as presented in Table 5.

Table 5. Education and Outreach Countermeasures (*30*)

Education	Outreach
• Awareness of speeding-related safety issues • Driver improvement courses • Educate about why and how speed limits are set • Educate repeat offenders • Educational and public information campaigns • Market research to determine how to reach high-risk drivers • Officer training • Progressive traffic education starting early • Signage to alert to upcoming treatments/changes • Walk as far off roadway as possible • Walk facing traffic	• Communicate study results to media and public • Community meetings • Events • Fact sheets • Mass emails • Mass mailings • Outreach support for enforcement • Public awareness campaigns • Presentations to local groups • Social marketing to create demand for speed management • Spokespeople

To identify factors related to successful publicity campaigns, Phillips et al. (*43*) conducted a meta-analysis, finding that alcohol-themed campaigns were more effective than speed-based ones. Personal and roadside message delivery showed greater effectiveness than mass media, although mass media remains valuable due to its broader reach. Newnam et al., (*44*) utilized an on-board Diagnostic tool (OBDII) to evaluate a behavior modification intervention for reducing over-speed violations among work-related drivers. Results showed a significant decrease in violations after drivers received weekly feedback and engaged in goal setting exercises. These findings offer practical guidance for improving work-related driving behavior. Beaton et al. (*40*) investigated public acceptance and support for automated speed enforcement (ASE) technologies in British Columbia through an online survey. The findings emphasize the need to address public perceptions and concerns to ensure successful deployment and expansion of ASE technologies for reducing transport injuries and deaths. Wright and Silberman (*45*) examined the relationship between exposure to dangerous driving behaviors in media and the perception of driving risk and behaviors among college students. The results confirmed that media exposure influences attitudes and behaviors related to driving, with movies having a greater impact than video games. The findings suggest a significant link between media exposure, attitudes, and reported driving behaviors, with theoretical explanations explored.

Planning and Policy

Effective management of over speeding necessitates well-defined planning and policy countermeasures that tackle root causes and enhance road safety. The NHTSA Safety Countermeasure Guide (Venkatraman et al., 2020) classifies speeding-related laws into speed limit regulations and aggressive driving laws. While altering maximum speed limits, whether reduced or increased, has shown significant impacts on speeds, crashes, and casualties (*46, 47, 48*), there is currently no evidence that general aggressive driving laws or increased penalties specifically influence aggressive driving and related crashes.

In general, planning and policy countermeasures align closely with the Vision Zero approach, which prioritizes safety in transportation systems to eliminate traffic fatalities and severe injuries. Numerous cities, including at least 68 in the United States, have pledged to adopt Vision Zero principles (*49*). For instance, the city of Boulder, Colorado implemented the Neighborhood Speed Management Program (NSMP) in 2018, incorporating it into the Transportation Master Plan and Vision Zero goals. This comprehensive program includes education, enforcement, and evaluation measures to reduce speeds on residential streets (*50*). Similarly, Richmond has launched a Speed Management Program as part of its Vision Zero Action Plan, acknowledging speeding as a significant factor in traffic fatalities. The program focuses on targeted interventions to manage and decrease speeding incidents (*51*). These examples highlight the integration of speeding countermeasures within the broader Vision Zero framework, fostering a collective effort to reduce traffic fatalities and serious injuries.

Data and Methodology

Michelin Data Description

Michelin event data provides speeding, harsh acceleration, and harsh braking events from individual vehicles. The following section provides a background on Michelin data used in this study.

Event Data

The 'Driving Events' service from Michelin Mobility Intelligence enables users to identify and count the occurrences of atypical driving events on a road network using GPS points. This service records five types of events that could potentially indicate safety concerns: harsh acceleration, harsh braking, excessive speeding, suspected collisions, and phone handling. By tracking these events, the service provides valuable insights into driving behaviors and road safety, helping users to pinpoint areas that may require attention or intervention to enhance overall road safety.

Michelin provides two types of event data to its users: raw driving event data and aggregated speeding and event data. The raw event data provides detailed information on unusual driving events within a road network, offering valuable insights for analysis and safety improvements. The data includes comprehensive information about each event, such as the timestamp and location of the start and end of events, road information, speed at the start of the event, the type of vehicle involved, and the GPS direction for the event. It also captures environmental conditions like temperature, the altitude of the sun, weather context, and rainfall intensity. We received Michelin data covering the periods from November 2022 to April 2023 and November 2023 to April 2024. The total number of harsh acceleration events, harsh braking events, and speeding events across these twelve months are shown in Figure 3. The geolocations of the start and end points of these events were used to conflate event data to road segments and determine the routes between the start and end points. Out of a total of 1,038,787 acceleration, braking, and speeding events, our conflation process successfully matched routes for 1,033,988 events.

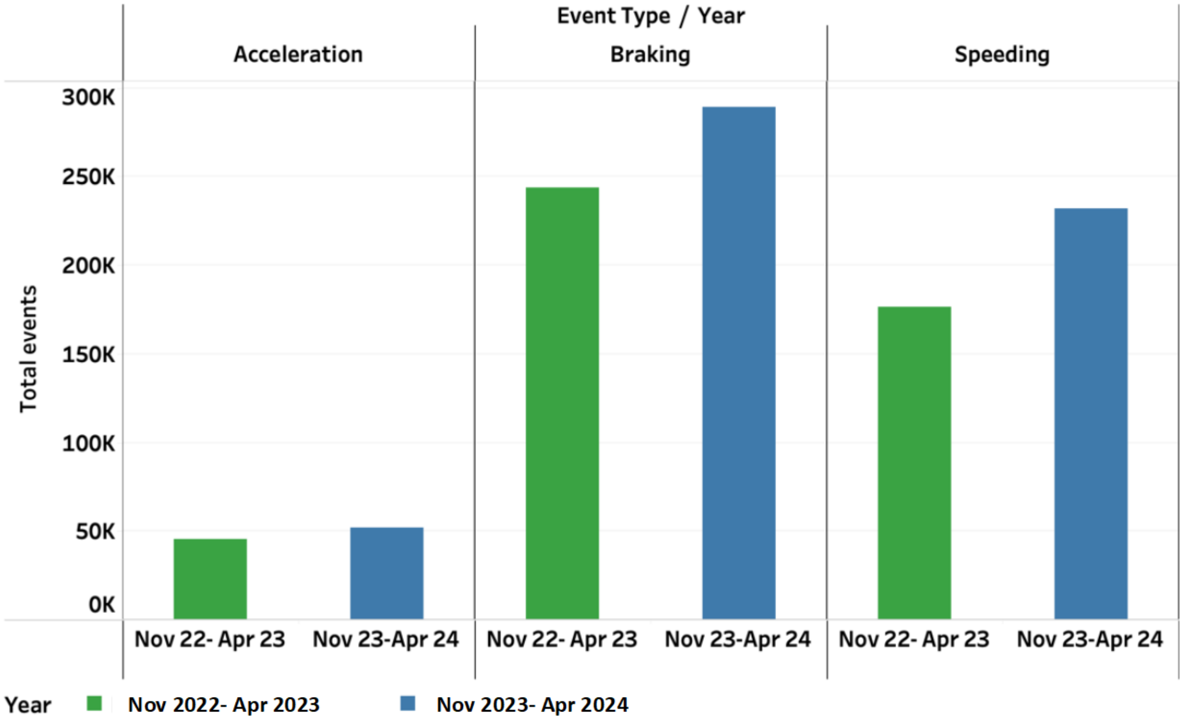


Figure 3 Total number of harsh acceleration, harsh braking, and speeding events

The aggregated driving event data includes the monthly average hourly number of events, as well as the number of records categorized by different speed ranges relative to the speed limit. We received the aggregated data for the same periods as the raw driving event data.

Origin-Destination Data

Another dataset provided by Michelin is the origin-destination (OD) data which includes the number of trips originating from or destined to census block groups that use a particular roadway in their routes. Michelin provided this data for the periods from November 2022 to April 2023 and November 2023 to April 2024. The number of trips originating from or destined to Prince George's County was the highest, followed by Charles County.

Controls are often used in before and after safety evaluations to accurately determine the impact of installed countermeasures on a roadway. The OD data can help normalize the number of driving events when using data from the treated site with temporal variation as a control, accounting for changes in vehicle penetration rates between the two periods. Initially, it is necessary to examine the correlation between the number of trips and the occurrences of different driving events per day. A linear relationship between the number of trips and the daily count of events, as shown in Figure 4, indicates that the rise in events correlates with an increase in trips. Therefore, normalizing the number of events by the number of trips is reasonable. For the daily temporal aggregation, normalization can be done by simply dividing the daily number of events by the daily number of trips. For the 15-minute temporal aggregation, the normalization factor can be obtained by dividing the daily trips by the total number of 15-minute intervals in a day (96 intervals).

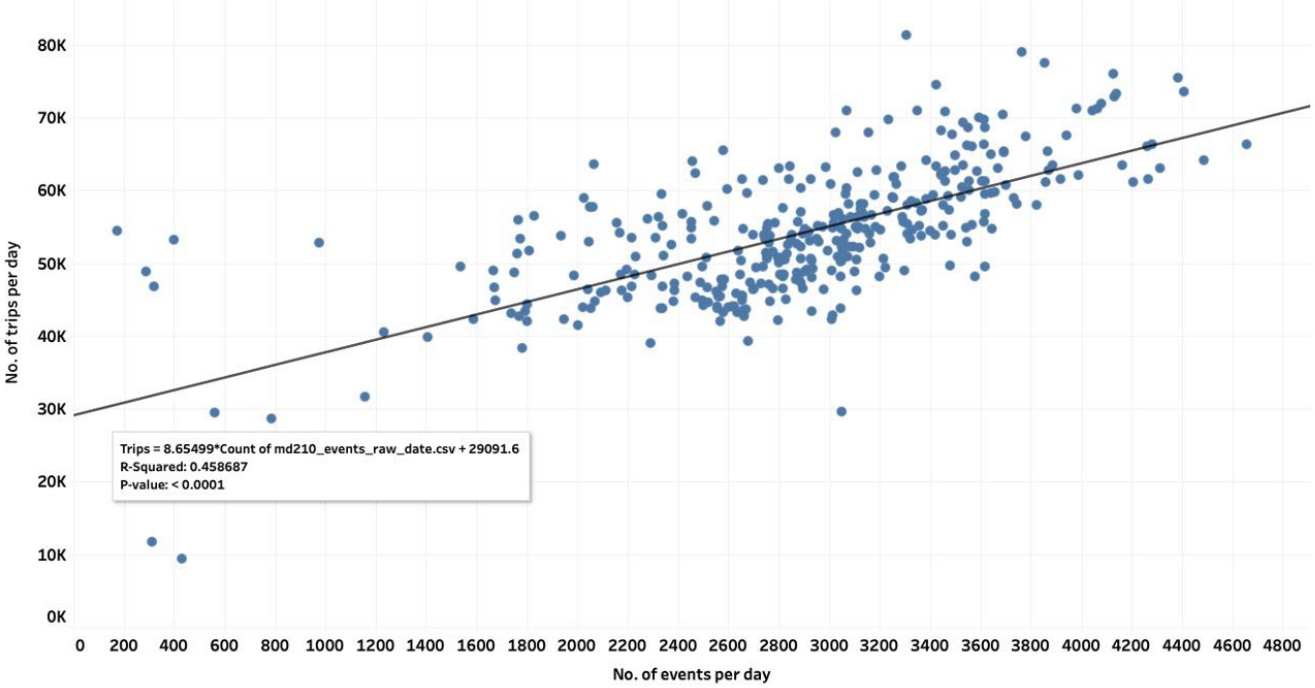


Figure 4 Number of trips per day vs. number of speeding, acceleration and braking events per day

Other Data Processing

This section describes the processing of data used to assess the performance of the countermeasures.

Probe Speed Data

Probe speed data, derived from connected vehicles, provides speed and travel time information for every minute across various segments. For this study, INRIX probe speed data was used to calculate the number of times when the traffic stream speed exceeded the speed limit by more than 5 mph. The process involves the following steps:

- Probe speed readings were collected every minute for each segment.
- These readings were aggregated into 15-minute intervals.
- Within each 15-minute interval, the number of 1-minute probe speed readings that were greater than the segment's speed limit plus 5 mph was counted.

Crash Data

This data is sourced from the Maryland State Police database (*2*). To use this data in the study, the geolocation and direction of each incident were used to conflate crashes to road segments.

The data was then aggregated for the before and after time periods to analyze changes in crash occurrences.

Segment Data

This data includes various attributes for each road segment, such as:

- Road class from INRIX TMC map data
- Speed limit from the MDOT State Highway Administration (*52*)
- Number of lanes from OpenStreetMap (OSM)
- Access points, which were extracted from road network geometry by counting the number of upstream segments for each segment
- Annual Average Daily Traffic (AADT) from MDOT (*53*)

The data and performance measures used in this study for control site selection and statistical analysis are presented in Table 6.

Table 6. Data and Performance Measures

Data Item	Data Source	Performance Measures
Harsh Braking	Michelin Event Data	Harsh breaking hotspot ranking, temporal trends
Harsh Acceleration	Michelin Event Data	Harsh acceleration hotspot ranking, temporal trends
Excessive Speeding	Michelin Event Data	Excessive speeding hotspot ranking, temporal trends
Trip Origin/Destination Data	Michelin-Arity	Origin/Destination of trips using MD 210, used to normalized daily event data.
Probe Speed Data	INRIX	Minute-by-minute speeds on each MD 210 XD segment (a total of 125 XDs)
Crash Data	MD Open Data Portal	Spatial and temporal crash trends by injury severity and crash type
Segment Data	INRIX, MDOT, OSM	Road class, speed limit, AADT, no. of lanes, no. of access points

Statistical Analysis

To address the issues of confounding bias and regression to the mean, a suitable method for evaluating the effect of an intervention in a before and after study involves comparing trends over time rather than simply comparing means. Two widely used statistical methods for before and after evaluations are ITS and DiD approaches. Both methodologies leverage longitudinal or time-series data collected over multiple time points.

Difference-in-Differences (DiD)

In cases where a before and after study design includes a concurrent control group that did not receive the intervention, the DiD approach can be used to improve inference. Analysis using DiD involves comparing the difference in outcomes before and after the intervention for the intervention group with the difference in outcomes for the control group over the same time periods. If Y_t represents the mean number of speeding, braking, or acceleration events at time t, "intervention" equals 1 for received and 0 if not received, and control equals 0 for the control site data and 1 for the treated site, a basic DiD model can be formulated as follows, a basic DiD model can be formulated as follows.

$$Y_t = \beta_0 + \beta_1 control + \beta_2 intervention + \beta_3 control \times intervention + \varepsilon_t \tag{1}$$

The parameter of interest here is β_3, the interaction term for control and intervention. β_3 estimates the difference in the differences in means between the treated and control groups across periods 0 and 1.

The primary assumption of the DiD approach is the "parallel trend" assumption, which assumes that the trends over time for the groups being compared would have been the same in the absence of the intervention. It is crucial to verify that pre-intervention trends were similar in both the intervention and control groups. For this purpose, a formal test can be performed where the treatment variable is interacted with time dummies (*54*). With three pre-treatment periods and three post-treatment periods, the test can be formulated as:

$$Y_t = \alpha_0 + \alpha_{-2} D_t + \alpha_{-1} D_t + \alpha_1 D_t + \alpha_2 D_t + \alpha_3 D_t + \mu_t \tag{2}$$

Significant coefficients for the interaction terms in the pre-treatment periods (α_{-1} and α_{-2}) would indicate that the parallel trends assumption does not hold.

Interrupted Time Series (ITS)

The ITS study design assesses the impact of an intervention by analyzing multiple measurements taken before and after the intervention. Unlike DiD models, ITS models estimate the effect by comparing the slopes of best-fit lines through pre- and post-intervention outcomes separately. The intervention's impact is modeled using a step function variable, which is zero before the intervention and one afterward. To estimate pre- and post-intervention slopes, ITS models require multiple measurements at evenly spaced time points around the intervention. There are two common types of ITS designs: (i) Single ITS and (ii) Controlled ITS.

While the strongest ITS design includes both an exposed and an unexposed group, ITS can still be used when only one group is available. If there are 1) sufficient measures before and after the intervention, 2) no other events affecting the outcome occur during the study period, 3) the intervention is implemented instantaneously, and 4) any cyclical patterns are accounted for, then ITS without an unexposed group can be a valid causal analysis method (*55, 56)*. This type of experimental design is known as a Single ITS design. The assumption in single ITS is that the level and trend in a given outcome measure in the group exposed to the intervention would have remained the same in the absence of the intervention.
If "time" represents the value of time from the start of the pre-intervention to the end of the post-intervention and "time.post " equals 0 if preintervention and otherwise equals the number of time periods, a single ITS model can be expressed as:

$$Y_t = \beta_0 + \beta_1 time_t + \beta_2 intervention_t + \beta_3 time.post_t + \varepsilon_t \tag{3}$$

Here, β_0 is the baseline level of the outcome at time 0, β_1 is the slope in the preintervention period, β_2 is the change in the mean number of events just after the start of the intervention, and β_3 is the difference in slopes or the change in trend between the post- and preintervention periods. An intervention might be considered effective in this model if either or both parameters β_2 and β_3 are significant and less than 0.

On the other hand, when both an exposed and an unexposed group are available, a more robust ITS analysis is possible. If the unexposed group is similar to the intervention group and the study period is long enough to capture multiple evenly spaced measures before and after the intervention, the unexposed group can help account for temporal changes that would affect the intervention group similarly had the intervention not occurred. In this case, the underlying assumption is that the level and trend of the group exposed to the intervention would have changed in the same way as was observed in the control group, had the intervention not been implemented (*28*). Such designs are termed as Controlled ITS designs. A controlled ITS model can be represented by the following equation:

$$\begin{aligned} Y_t = \beta_0 + \beta_1 time_t + \beta_2 intervention_t + \beta_3 time.post_t + \beta_4 control_t + \beta_5 control \times time_t \\ + \beta_6 control \times intervention_t + \\ \beta_7 control_t \times intervention_t \times time.post_t + \varepsilon_t \end{aligned} \tag{4}$$

Here, β_5 measures the difference between the two groups on the preintervention slope, β_6 compares the groups on the change in intercept at the start of the intervention, and β_7 compares the groups on the change in slope between periods. An intervention might be considered effective in this model if either or both parameters β_6 or β_7 are significant and less than 0.

Control Site Selection

Difference-in-differences and controlled interrupted time series analyses rely on an additional dataset to calculate a counterfactual. This data can come from the same site with temporal variation or from a different site at the same time, referred to as a control site. Control sites are locations that are similar in attributes to the treated location where the countermeasures are installed. For the before and after comparison of safety countermeasures, we employed a novel approach to select control sites using a similarity distance measure called Gower distance. Gower distance is particularly useful as it can handle both categorical and numerical values. It identifies the similarity between data objects by calculating the distance based on their features. If the distance is small, the objects are highly similar, and vice versa. The distance for each variable type is calculated first, followed by a linear combination (most simply an average) using user-specified weights to create the final distance matrix (*57*).

The first step in identifying a suitable control site is to select the area for analysis based on the locations of the countermeasures. This can be done using the segments that contain the countermeasures. To develop a list of candidate sites for analysis, the road network map of the entire state can be utilized. The list is created by considering all possible combinations of start and end segments along routes. Routes that are similar in length to the treated area are then considered for analysis. For each route, the following features can be used to calculate the Gower distance:

- Number of crashes in recent years

- Percent change in crashes
- Median functional class
- Minimum functional class
- Maximum functional class
- Median no. of lanes
- Minimum no. of lanes
- Maximum no. of lanes
- Mean AADT
- Range of AADT
- Maximum rise in AADT for consecutive segments
- Maximum drop in AADT for consecutive segments
- Mean speed limit
- Mean reference speed
- No. of traffic signals per mile
- No. of entry points per mile
- No. of exit points per mile

Some of these selected variables may be highly correlated with one another. Principal Component Analysis (PCA) can be employed to select variables that retain the most information from the dataset. PCA is a technique that transforms high-dimensional data into lower dimensions while retaining as much information as possible. This results in a set of principal components, where the first few components explain most of the variance in the dataset. As shown in Figure 5, the first three principal components account for approximately 75% of the total variance.

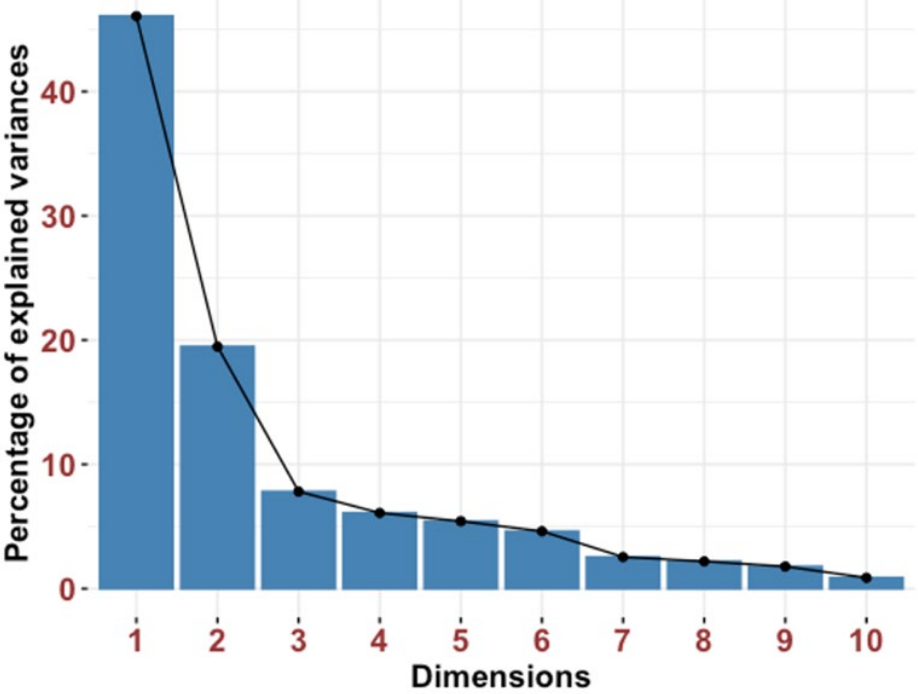


Figure 5 Variance explained by each principal component

In PCA, the square cosine (cos2) values are used to evaluate how well each variable is represented by the components. A low cos2 value indicates that the variable is not well represented by the component, while a high cos2 value indicates a good representation. The factor map provides a visual representation of the projection of the observed variables onto the plane of the principal components, with the distance from the origin representing the cos2 of the variables. Figure 6 shows a factor map using the first two principal components. We can see that the variables "reference_speed_mean" and "speed_limit_mean" are correlated, as indicated by their close proximity. However, the cos2 of "reference_speed_mean" is higher for these two components. Therefore, instead of including both variables, only "reference_speed_mean" can be included in the Gower distance calculation.

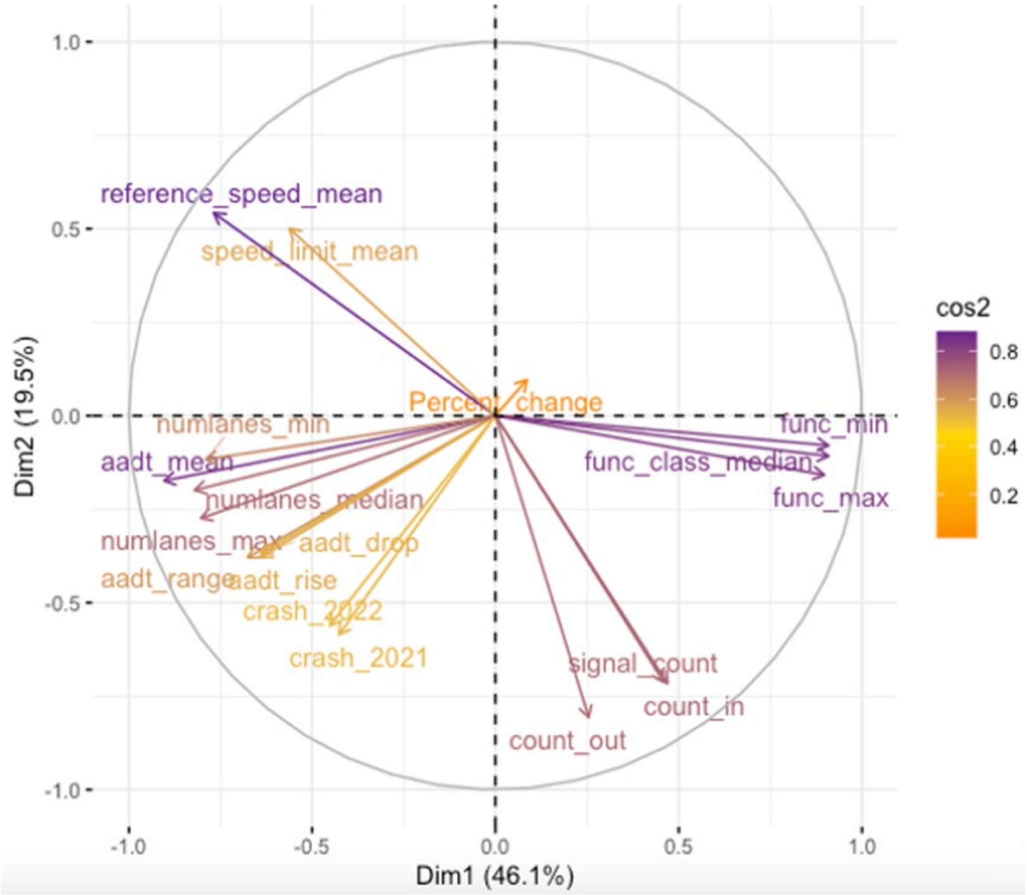
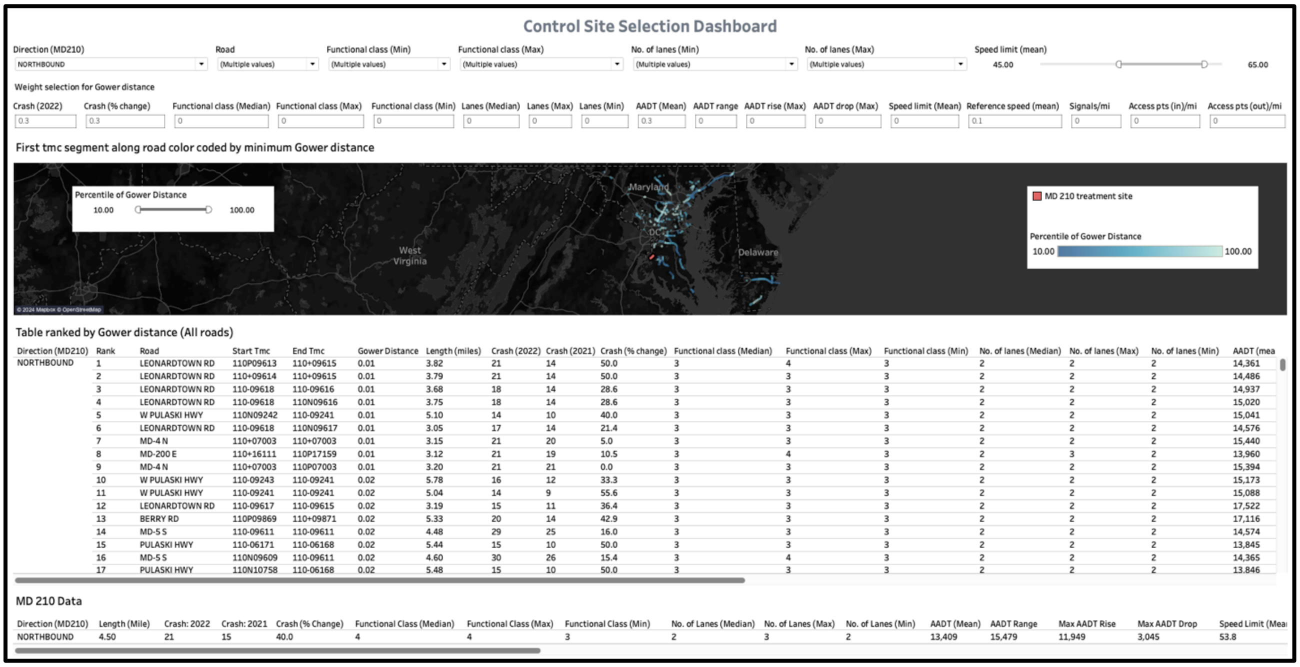


Figure 6 Variable factor map of the first two principal components

After running PCA, a dashboard can be utilized to determine the final control sites by performing a sensitivity analysis with different weights of the variables. The variables can be added as drop-down filters, and initial filters can be applied before specifying the weights for the Gower distance calculation. These initial filters can be selected based on the attributes of the treated site. For instance, the following filters can be applied:

- Functional class (Min): 2, 3, 4
- Functional class (Max): 3, 4
- No. of lanes (Min): 1, 2
- No. of lanes (Max): 2, 3, 4
- Speed limit (Mean): 45 mph to 65 mph

A Tableau dashboard designed to select suitable control sites using Gower distance is shown in Figure 7. The top portion of the dashboard allows users to filter for various parameters such as the number of lanes, AADT, number of crashes, etc. The dashboard includes a section to specify weights for the Gower distance calculation, with weights ranging from 0 to 1. After specifying the weights, the final Gower distance is computed as a weighted average. A table populates with the list of sites in ascending order of Gower distance. This table also displays the attributes for each site. Additionally, for quick comparison, another table at the bottom of the dashboard shows the same attributes for the treated site, which in this case is MD 210.



Control Site Selection Dashboard

Direction (MD210): NORTHBOUND
Road: (Multiple values)
Functional class (Min): (Multiple values)
Functional class (Max): (Multiple values)
No. of lanes (Min): (Multiple values)
No. of lanes (Max): (Multiple values)
Speed limit (mean): 45.00 – 65.00

Weight selection for Gower distance

Crash (2022)	Crash (% change)	Functional class (Median)	Functional class (Max)	Functional class (Min)	Lanes (Median)	Lanes (Max)	Lanes (Min)	AADT (Mean)	AADT range	AADT rise (Max)	AADT drop (Max)	Speed limit (Mean)	Reference speed (mean)	Signals/mi	Access pts (in)/mi	Access pts (out)/mi
0.3	0.3	0	0	0	0	0	0	0.3	0	0	0	0	0.1	0	0	0

First tmc segment along road color coded by minimum Gower distance

Table ranked by Gower distance (All roads)

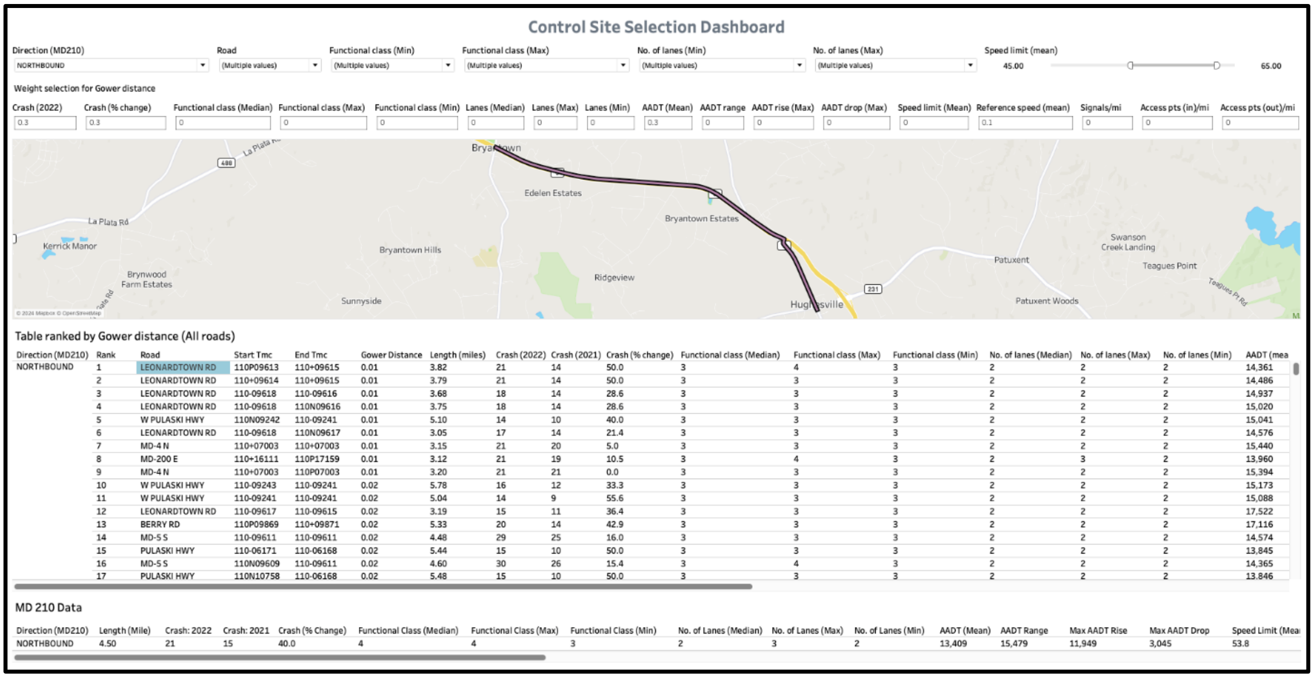
Direction (MD210)	Rank	Road	Start Tmc	End Tmc	Gower Distance	Length (miles)	Crash (2022)	Crash (2021)	Crash (% change)	Functional class (Median)	Functional class (Max)	Functional class (Min)	No. of lanes (Median)	No. of lanes (Max)	No. of lanes (Min)	AADT (mea
NORTHBOUND	1	LEONARDTOWN RD	110P09613	110+09615	0.01	3.82	21	14	50.0	3	4	3	2	2	2	14,361
	2	LEONARDTOWN RD	110+09614	110+09615	0.01	3.79	21	14	50.0	3	3	3	2	2	2	14,486
	3	LEONARDTOWN RD	110-09618	110-09616	0.01	3.68	18	14	28.6	3	3	3	2	2	2	14,937
	4	LEONARDTOWN RD	110-09618	110N09616	0.01	3.75	18	14	28.6	3	3	3	2	2	2	15,020
	5	W PULASKI HWY	110N09242	110-09241	0.01	5.10	14	10	40.0	3	3	3	2	2	2	15,041
	6	LEONARDTOWN RD	110-09618	110N09617	0.01	3.05	17	14	21.4	3	3	3	2	2	2	14,576
	7	MD-4 N	110+07003	110+07003	0.01	3.15	21	20	5.0	3	3	3	2	2	2	15,440
	8	MD-200 E	110+16111	110P17159	0.01	3.12	21	19	10.5	3	4	3	2	3	2	13,960
	9	MD-4 N	110+07003	110P07003	0.01	3.20	21	21	0.0	3	3	3	2	2	2	15,394
	10	W PULASKI HWY	110-09243	110-09241	0.02	5.78	16	12	33.3	3	3	3	2	2	2	15,173
	11	W PULASKI HWY	110-09241	110-09241	0.02	5.04	14	9	55.6	3	3	3	2	2	2	15,088
	12	LEONARDTOWN RD	110-09617	110-09615	0.02	3.19	15	11	36.4	3	3	3	2	2	2	17,522
	13	BERRY RD	110P09869	110+09871	0.02	5.33	20	14	42.9	3	3	3	2	2	2	17,116
	14	MD-5 S	110-09611	110-09611	0.02	4.48	29	25	16.0	3	3	3	2	2	2	14,574
	15	PULASKI HWY	110-06171	110-06168	0.02	5.44	15	10	50.0	3	3	3	2	2	2	13,845
	16	MD-5 S	110N09609	110-09611	0.02	4.60	30	26	15.4	3	4	3	2	2	2	14,365
	17	PULASKI HWY	110N10758	110-06168	0.02	5.48	15	10	50.0	3	3	3	2	2	2	13,846

MD 210 Data

Direction (MD210)	Length (Mile)	Crash: 2022	Crash: 2021	Crash (% Change)	Functional Class (Median)	Functional Class (Max)	Functional Class (Min)	No. of Lanes (Median)	No. of Lanes (Max)	No. of Lanes (Min)	AADT (Mean)	AADT Range	Max AADT Rise	Max AADT Drop	Speed Limit (Mea
NORTHBOUND	4.50	21	15	40.0	4	4	3	2	3	2	13,409	15,479	11,949	3,045	53.8

Figure 7 Control site selection dashboard

Another advantage of using a dashboard is the ability to view potential control sites on a map, as illustrated in Figure 8. This visual exploration is important for making an informed final selection.



Control Site Selection Dashboard

Direction (MD210): NORTHBOUND
Road: (Multiple values)
Functional class (Min): (Multiple values)
Functional class (Max): (Multiple values)
No. of lanes (Min): (Multiple values)
No. of lanes (Max): (Multiple values)
Speed limit (mean): 45.00 – 65.00

Weight selection for Gower distance

Crash (2022)	Crash (% change)	Functional class (Median)	Functional class (Max)	Functional class (Min)	Lanes (Median)	Lanes (Max)	Lanes (Min)	AADT (Mean)	AADT range	AADT rise (Max)	AADT drop (Max)	Speed limit (Mean)	Reference speed (mean)	Signals/mi	Access pts (in)/mi	Access pts (out)/mi
0.3	0.3	0	0	0	0	0	0	0.3	0	0	0	0	0.1	0	0	0

Table ranked by Gower distance (All roads)

Direction (MD210)	Rank	Road	Start Tmc	End Tmc	Gower Distance	Length (miles)	Crash (2022)	Crash (2021)	Crash (% change)	Functional class (Median)	Functional class (Max)	Functional class (Min)	No. of lanes (Median)	No. of lanes (Max)	No. of lanes (Min)	AADT (mea
NORTHBOUND	1	LEONARDTOWN RD	110P09613	110+09615	0.01	3.82	21	14	50.0	3	4	3	2	2	2	14,361
	2	LEONARDTOWN RD	110+09614	110+09615	0.01	3.79	21	14	50.0	3	3	3	2	2	2	14,486
	3	LEONARDTOWN RD	110-09618	110-09616	0.01	3.68	18	14	28.6	3	3	3	2	2	2	14,937
	4	LEONARDTOWN RD	110-09618	110N09616	0.01	3.75	18	14	28.6	3	3	3	2	2	2	15,020
	5	W PULASKI HWY	110N09242	110-09241	0.01	5.10	14	10	40.0	3	3	3	2	2	2	15,041
	6	LEONARDTOWN RD	110-09618	110N09617	0.01	3.05	17	14	21.4	3	3	3	2	2	2	14,576
	7	MD-4 N	110+07003	110+07003	0.01	3.15	21	20	5.0	3	3	3	2	2	2	15,440
	8	MD-200 E	110+16111	110P17159	0.01	3.12	21	19	10.5	3	4	3	2	3	2	13,960
	9	MD-4 N	110+07003	110P07003	0.01	3.20	21	21	0.0	3	3	3	2	2	2	15,394
	10	W PULASKI HWY	110-09243	110-09241	0.02	5.78	16	12	33.3	3	3	3	2	2	2	15,173
	11	W PULASKI HWY	110-09241	110-09241	0.02	5.04	14	9	55.6	3	3	3	2	2	2	15,088
	12	LEONARDTOWN RD	110-09617	110-09615	0.02	3.19	15	11	36.4	3	3	3	2	2	2	17,522
	13	BERRY RD	110P09869	110+09871	0.02	5.33	20	14	42.9	3	3	3	2	2	2	17,116
	14	MD-5 S	110-09611	110-09611	0.02	4.48	29	25	16.0	3	3	3	2	2	2	14,574
	15	PULASKI HWY	110-06171	110-06168	0.02	5.44	15	10	50.0	3	3	3	2	2	2	13,845
	16	MD-5 S	110N09609	110-09611	0.02	4.60	30	26	15.4	3	4	3	2	2	2	14,365
	17	PULASKI HWY	110N10758	110-06168	0.02	5.48	15	10	50.0	3	3	3	2	2	2	13,846

MD 210 Data

Direction (MD210)	Length (Mile)	Crash: 2022	Crash: 2021	Crash (% Change)	Functional Class (Median)	Functional Class (Max)	Functional Class (Min)	No. of Lanes (Median)	No. of Lanes (Max)	No. of Lanes (Min)	AADT (Mean)	AADT Range	Max AADT Rise	Max AADT Drop	Speed Limit (Mea
NORTHBOUND	4.50	21	15	40.0	4	4	3	2	3	2	13,409	15,479	11,949	3,045	53.8

Figure 8 Dashboard showing the location of the selected site

A sensitivity analysis can be conducted by varying the weights used in the Gower distance calculation. Multiple weight combination scenarios can be considered, with each scenario generating a list of multiple potential control sites. The final selection of control sites should be based on the frequency with which each site appears across these different scenarios and a visual inspection of the sites on a map. To ensure a robust comparative analysis, at least two control sites should be selected for each direction.

Results

Note that many of the installed countermeasures were damaged shortly after installation, especially the flex posts.

For the analysis, we selected a 4.5-mile stretch along MD 210 where the countermeasures were installed as shown in Figure 9. Using the methodology described in the previous section, we selected control sites for this portion of MD 210. After running PCA, we performed a sensitivity analysis using different weights for the selected variables as shown in Table 7 to determine the final control sites. We selected two control sites for each direction of MD 210. For the analysis with Michelin data, we selected another portion of MD 210 that had the minimum Gower distance as a control site. The locations of the sites are shown in Figure 10.

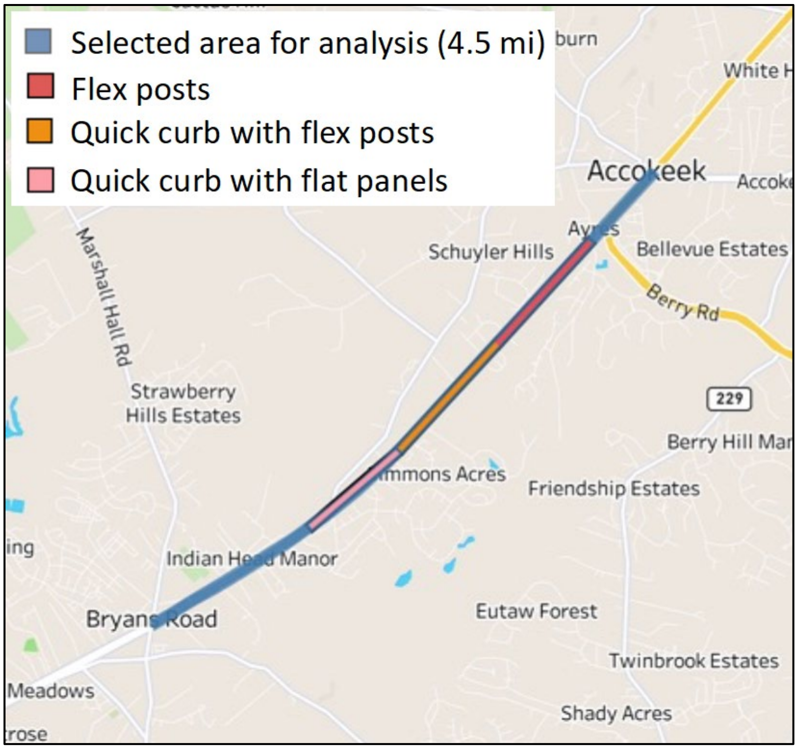
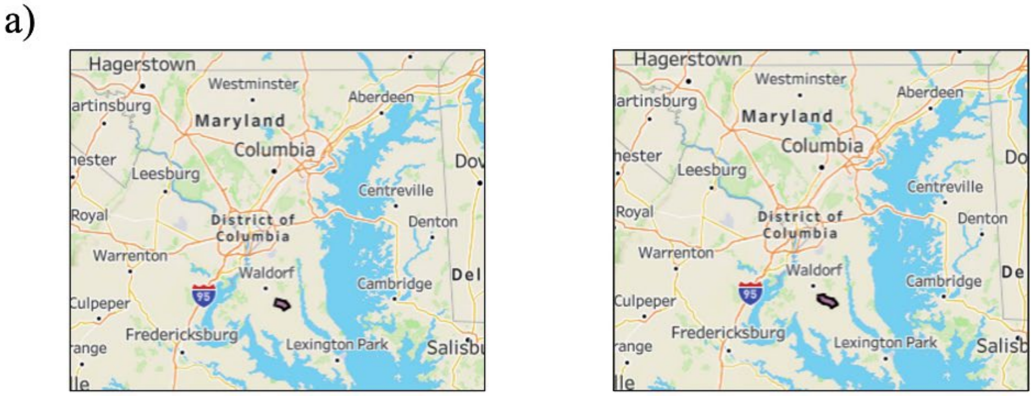


Figure 9 Map showing selected area for analysis and location of countermeasures

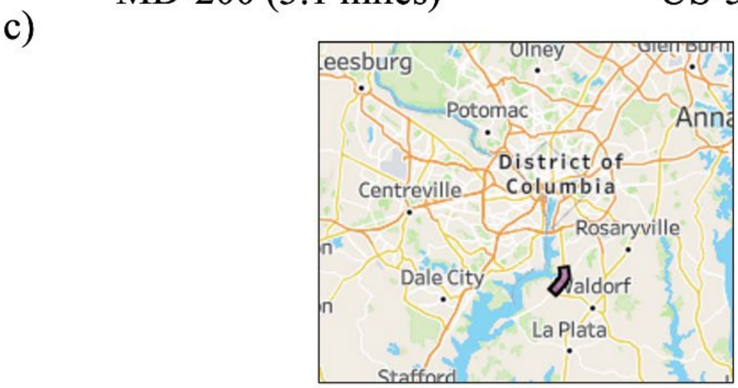
Table 7. Variable weights for different scenarios in Gower distance calculation

Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Crashes (2022)	0.4	0.3	0.3	0.2	0.2	0.1
Crash (% change)	0.2	0.2	0.2	0.2	0.1	0.1
Functional class (Median)		0.1		0.1	0.1	0.1
Lanes (Median)			0.1	0.1		
AADT (Mean)	0.2	0.2	0.2	0.2	0.1	0.1
AADT (Range)					0.1	0.1
Reference speed (Mean)	0.1	0.1	0.1	0.1	0.1	0.1
Signals/mi	0.1	0.1	0.1	0.1	0.1	0.1
Access pts (in)/mi					0.1	0.1
Access pts (out)/mi					0.1	0.1



MD-5 (3.8 miles) MD-5 (5.6 miles)

MD-200 (3.1 miles) US-50 (4.6 miles)



MD-210 (4.1 miles)

Figure 10 a) Control sites for analysis using probe data (Northbound direction); b) Control sites for analysis using probe data (Southbound direction); c) Control site for analysis using Michelin data

After selecting the control sites, we conducted statistical analysis using ITS and DiD approaches as outlined in the methods section. For probe data, the outcome measure was the number of speed readings exceeding the speed limit by 5 mph within a given time period. For Michelin data, the outcome measures were the counts of speeding, acceleration, and braking events. We used two temporal aggregations: 15 minutes and 1 day. For ITS, a continuous time period was used for the before and after comparisons. For DiD, two different lengths of 1 week and 1 month were used for the before and after periods. The duration of the before and after periods for both the methods are shown in Figure 11. For probe data, the control sites shown in Figure 11(a) and

Figure 11(b) were used, while for Michelin data, the control site shown in Figure 11(c) was used. Additionally, MD 210 data from the previous year were used as a control in the analysis as this was the only road with Michelin data available for his project.

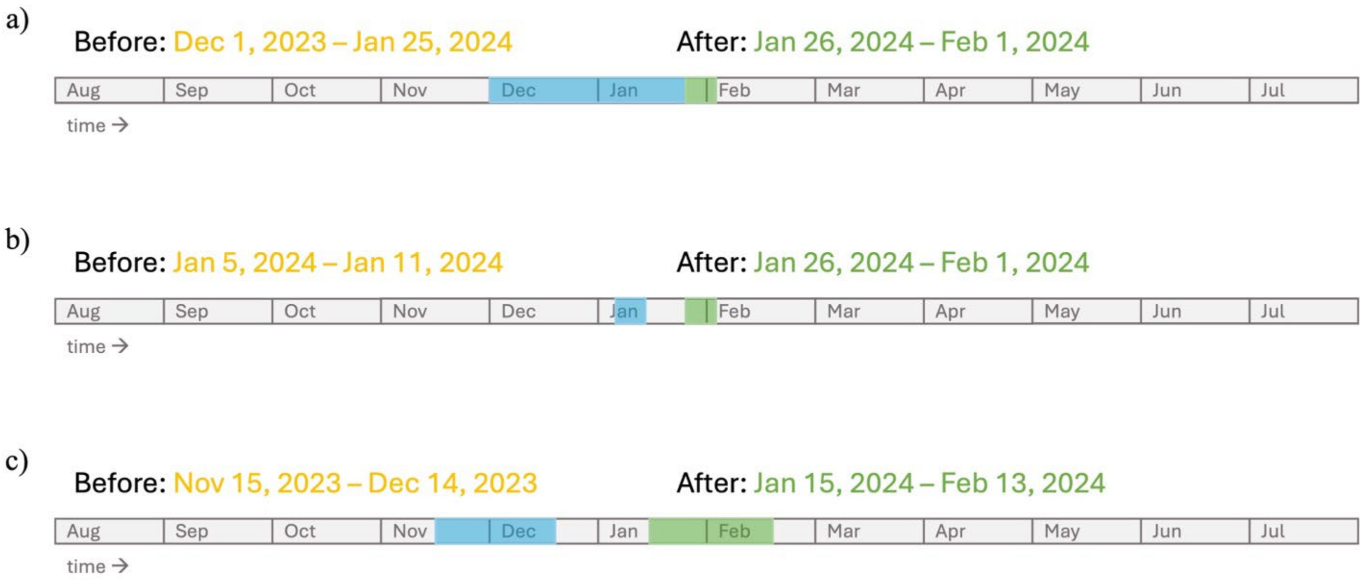


Figure 11 a) Before and after periods for ITS method; b) Before and after periods for DID method with 1-week temporal aggregation; c) Before and after periods for DID method with 1-month temporal aggregation

There were notable differences in the robustness of the ITS and DiD methods. The ITS method was particularly sensitive to daily variations and short-lived treatments. To explore this, we tested a different after period of January 26 to January 31. We noticed that for most scenarios, ITS was sensitive to daily variations in the number of events. For example, using MD-5 as the control site with probe data, we observed a decrease in the daily trend for both 6-day and 7-day after periods. However, the trend was significant for the 6-day after period, but not significant for the 7-day after period. In contrast, the DiD method, which compares differences in mean outcomes over the same time periods rather than trends, is less sensitive to daily fluctuations in the number of events. Another drawback of the ITS method is the necessity for continuous before and after periods, preventing the exclusion of December, a month with many holidays, from the analysis. In contrast, DiD offered the flexibility to select before and after periods that minimize the impact of holidays. For these reasons, we decided to use DiD for evaluating the impact of the countermeasures.

In the analysis, most combinations of temporal aggregations, before and after period lengths, and control sites did not provide sufficient evidence to conclude the effectiveness of the installed countermeasures. Table 3 presents the results of the DiD analysis for Michelin speeding events, which mostly indicate a decrease in the mean number of speeding events at the treated site compared to the control site. However, these decreases were statistically insignificant in 12 out of 16 cases.

Table 8. Results of the DiD analysis for Michelin speeding events

Direction	Control	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Week	15 mins	Yes	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	No	Decrease	Yes
			1 day	Yes	Decrease	Yes
	Downstream of the treatment locations	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	Yes	Decrease	No
			1 day	Yes	Decrease	No
Southbound	Previous year at the treatment locations	Week	15 mins	Yes	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	No	Decrease	Yes
			1 day	No	Decrease	Yes
	Upstream of the treatment locations	Week	15 mins	No	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	Yes	Increase	No
			1 day	Yes	Increase	No

Similar results were observed for other events and when analyzing probe data, where no significant impact of the countermeasures was detected as shown in Table 9, Table 10 and Table 11.

Table 9. Results of the DiD analysis for Michelin braking events

Direction	Control	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Week	15 mins	Yes	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	Yes	Decrease	No
			1 day	Yes	Decrease	No
	Downstream of the treatment locations	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	Yes	Increase	Yes
			1 day	Yes	Increase	No
Southbound	Previous year at the treatment locations	Week	15 mins	Yes	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	Yes	Increase	Yes
			1 day	Yes	Increase	No
	Upstream of the treatment locations	Week	15 mins	No	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	Yes	Increase	No
			1 day	Yes	Increase	No

Table 10. Results of the DiD analysis for Michelin acceleration events

Direction	Control	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Week	15 mins	No	Increase	No
			1 day	No	Increase	No
		Month	15 mins	Yes	Decrease	No
			1 day	Yes	Decrease	No
	Downstream of the treatment locations	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	Yes	Increase	Yes
			1 day	Yes	Increase	No
Southbound	Previous year at the treatment locations	Week	15 mins	Yes	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	No	Increase	No
			1 day	Yes	Increase	No
	Upstream of the treatment locations	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	Yes	Increase	Yes
			1 day	Yes	Increase	Yes

Table 11. Results of the DiD analysis for probe data

Direction	Control	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Week	15 mins	No	Increase	No
			1 day	No	Increase	No
		Month	15 mins	No	Decrease	Yes
			1 day	No	Decrease	Yes
	MD-200 (3.1 miles)	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	No	Increase	Yes
			1 day	No	Increase	No
	US-50 (4.6 miles)	Week	15 mins	No	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	No	Decrease	Yes
			1 day	No	Decrease	No
Southbound	Previous year at the treatment locations	Week	15 mins	No	Increase	No
			1 day	No	Increase	No
		Month	15 mins	No	Decrease	Yes
			1 day	No	Decrease	Yes
	MD-200 (3.1 miles)	Week	15 mins	No	Decrease	No
			1 day	Yes	Decrease	No
		Month	15 mins	No	Increase	Yes
			1 day	No	Increase	No
	US-50 (4.6 miles)	Week	15 mins	No	Increase	No
			1 day	Yes	Increase	No
		Month	15 mins	No	Decrease	Yes
			1 day	No	Decrease	No

Before interpreting the results of the DiD analysis, it is essential to verify the validity of the parallel trends assumption. This assumption was checked following the test described in the method section. For each dataset and scenario, we conducted this test prior to analysis. For probe data, the parallel trends assumption was met in only 4 out of 24 cases. In contrast, the assumption was mostly valid for the Michelin events. One possible explanation for this discrepancy lies in the definition of events for each dataset. The parallel trends assumption checks whether the change in the mean number of events during the before periods is similar for both treated and control sites, a change that is often correlated with traffic volumes. Since the number of Michelin events correlates with traffic volumes, the assumption was generally valid. However, probe speeding events do not have a direct correlation with traffic volumes. For example, with a temporal aggregation of 15 minutes, the possible maximum number of speeding events is 15, given the 1-minute granularity of probe data, regardless of traffic volumes.

We also evaluated the effectiveness of each countermeasure separately. First, we selected the segments containing each countermeasure and performed DiD analysis using data from the previous year as the control. The results were mostly insignificant for both probe data and Michelin data. The parallel trends assumption was not valid in cases where significant results were observed. Results of this analysis using Michelin speeding event data, Michelin braking event data, Michelin acceleration event data, and probe data are shown in Table 12, Table 13, Table 14, and Table 15 respectively.

Table 12. Results of the DiD analysis with Michelin speeding event data for each countermeasure

Direction	Control	Counter-measure	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Flex post	Week	15 mins	No	Decrease	Yes
		Quick curb	Week	15 mins	No	Decrease	No
		Flat panels	Week	15 mins	Yes	Decrease	No
Southbound	Previous year at the treatment locations	Flex post	Week	15 mins	Yes	Increase	No
		Quick curb	Week	15 mins	Yes	Decrease	No
		Flat panels	Week	15 mins	Yes	Decrease	No

Table 13. Results of the DiD analysis with Michelin braking event data for each countermeasure

Direction	Control	Counter-measure	Before/After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Flex post	Week	15 mins	Yes	Increase	No
		Quick curb	Week	15 mins	No	Increase	No
		Flat panels	Week	15 mins	Yes	Increase	No
Southbound	Previous year at the treatment locations	Flex post	Week	15 mins	Yes	Increase	No
		Quick curb	Week	15 mins	Yes	Increase	No
		Flat panels	Week	15 mins	No	Increase	No

Table 14. Results of the DiD analysis with Michelin acceleration event data for each countermeasure

Direction	Control	Counter-measure	Before/ After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Flex post	Week	15 mins	Yes	Increase	No
		Quick curb	Week	15 mins	Yes	Increase	No
		Flat panels	Week	15 mins	Yes	Decrease	No
Southbound	Previous year at the treatment locations	Flex post	Week	15 mins	Yes	Decrease	No
		Quick curb	Week	15 mins	Yes	Decrease	No
		Flat panels	Week	15 mins	Yes	Increase	No

Table 15. Results of the DiD analysis with probe data for each countermeasure

Direction	Control	Counter-measure	Before/ After period	Aggregation	Assumption valid?	Result	Significant result?
Northbound	Previous year at the treatment locations	Flex post	Week	15 mins	No	Decrease	Yes
		Quick curb	Week	15 mins	No	Decrease	No
		Flat panels	Week	15 mins	No	Increase	No
Southbound	Previous year at the treatment locations	Flex post	Week	15 mins	No	Decrease	No
		Quick curb	Week	15 mins	No	Increase	No
		Flat panels	Week	15 mins	No	Increase	No

Conclusions

In this research, a custom and robust methodological framework was developed to measure the effectiveness of traffic safety countermeasures on MD 210. First, the team mapped raw Michelin event data to the MD 210 map. Next, the research team employed Gower distance as a means to narrow the space of potential control sites based on functional similarity to MD 210. These control sites were then used as the counterfactual required by the Interrupted Time Series and Difference in Difference statistical tests. In contrast to the past transportation safety literature on ITS and DiD, we did not directly measure crash counts or rates. Instead, we applied these methods to probe vehicle speed data and event data, with a focus on speeding, harsh acceleration, and harsh braking events as a measurement of dangerous driving behavior.

Our framework found that recent countermeasures applied to MD 210 resulted in no discernable decrease in dangerous driving behavior. This result was consistent for both the ITS and DiD version of the framework. However, we found that DiD allows us to be much more confident in this result, given the limitations of our data and treatment period, than ITS. In particular, we found ITS to be far more sensitive to small changes in the definition of the before and after period. DiD on the other hand consistently found no result across a plethora of combinations of before-after periods, as well as the temporal granularity for which we aggregated the event data. The research team also conducted an analysis to isolate the effects of individual countermeasures on MD 210. However, none of the countermeasures showed a statistically significant reduction in dangerous driving behavior. It is worth noting that many of the countermeasures, especially the flex-posts were damaged shortly after installation. However, even the short-duration studies just before and after installation showed no impact on the safety performance measures.

Implementation Plan

This research established a robust and rigorous analysis procedure to assess the effectiveness of any safety intervention. The research team has provided MDOT District 3 with detailed documentation of the data needs and methodology to promote the continued use of the analysis process. Future projects related to this research include the application of the methodology to other safety interventions across the state. In addition, the development of automated online tools would streamline the analysis process and promote the regular, widespread use of the analysis methods.

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