PILOT PROJECT

Dynamic Warning Systems to Alert Motorists to the Presence of Bicyclists

FINAL REPORT

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  Montana State University
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16. Abstract

This project piloted dynamic warning signs aimed at improving road safety for people bicycling on rural roads where motor vehicles and bicycles must share a lane. This project used existing technologies in a new way, by combining an existing bicycle detection (inductive loop) system with flashing lights to alert drivers to the presence of bicycles. The flashing lights are triggered when a person rides a bicycle over the inductive loops, making this system "dynamic."

Two warning systems were installed each on rural roads in Oregon, Colorado and Idaho between spring 2018 and spring 2020 for a total of six systems. Data was collected using video cameras and road tubes or radar to monitor system reliability in detecting bicycles in mixed traffic and assess changes in driver speeds with the warning systems. A survey was used to assess facility owner perceptions of the systems.

The warning systems correctly detected bicycles approximately 86 percent to 94 percent of the time during the study. Mean vehicle speeds were reduced for three of the four warning systems analyzed after the signs were installed. Based on this pilot project, dynamic warning systems are recommended as a tool that may improve road safety for people bicycling on rural roads.

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Abstract

This project piloted dynamic warning signs aimed at improving road safety for people bicycling on rural roads by using existing technologies in a new way. This project combined Eco Counter's Zelt bicycle detection (inductive loop) system with flashing lights to alert drivers to the presence of bicycles. The flashing lights are triggered when a person rides a bicycle over the inductive loops, making this system "dynamic." The warning systems correctly detected bicycles approximately 86 percent to 94 percent of the time. Mean vehicle speeds were reduced for three of the four warning systems analyzed after the signs were installed. However, the analysis suggested that only a small proportion of total variability in vehicle speed (from 1.4 % to 3.3%) may be explained by the dynamic warning signs. Based on this pilot project, dynamic warning systems are recommended as a tool that may improve road safety for people bicycling on rural roads.

Disclaimer

This work was conducted under a grant from the Coordinated Technology Implementation Program (CTIP) and the Accelerated Innovation Deployment (AID) Demonstration Project through the U.S. Fish and Wildlife Service (USFWS). Any opinions, findings and conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the funding agencies.

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Cover photos: Dynamic Warning Signs (photos courtesy WTI, ODOT, Boundary County)

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ADT	average daily traffic
AID	Accelerated Innovation Deployment Demonstration Project
CTIP	Coordinated Technology Implementation Program
COLM	Colorado National Monument
DOT	Department of Transportation
MP	Milepost
mph	miles per hour
ped	pedestrian
NPS	National Park Service
ODOT	Oregon Department of Transportation
WTI	The Western Transportation Institute

1. PROJECT OVERVIEW

Bicycle use has been increasing nationwide, and many people enjoy riding bicycles along rural roads in scenic places. These roads often have high speed traffic, narrow or no shoulders, and/or limited sight distances that put people on bicycles in a particularly vulnerable position. Engineering solutions such as wider shoulders or separated paths are not always possible due to political, topographic, or economic constraints.

1.1. Project Statement

Finding simple solutions to make rural roads safer for people on bicycles has been identified as a priority by the Federal Land Management Agencies under the Coordinated Technology Implementation Program (CTIP). This project aims to improve road safety for people bicycling and driving on rural roads by using existing technologies in a new way.

1.2. Project Solution

This project explores a new application of existing bicycle detection technologies, where an existing detection system (inductive loops) is combined with flashing lights to alert drivers to the presence of bicycles along rural roads where motor vehicles and bicycles share a lane. The system's lights will flash only when a person rides a bicycle over the inductive loops, making this system "dynamic." This warning system combines Eco-Counter's Zelt inductive loop system with "Bicycle Ahead" signage and flashing lights to alert drivers to the presence of bicycles. Inductive loops are an existing technology typically used to detect motor vehicles. Systems that can detect cyclists, differentiating them from motor vehicles, and trigger a warning system for drivers have not been studied in detail.

Inductive loops consist of wires installed under the surface of the pavement in a loop configuration. They use magnetic fields to generate an electrical current. A sensor detects changes in the magnetic field when metal parts of a bicycle pass over the loops. Inductive loops are commonly used by transportation agencies, and they are easy to maintain.

2. ACTIVITIES PERFORMED

Two warning systems were installed on rural Hwy 242 near Sisters, Oregon, two were installed on Rim Rock Dr. in Colorado National Monument near Grand Junction, Colorado and two were installed on Riverside Road near Bonners Ferry, Idaho between spring 2018 and spring 2020. Data was collected using video cameras and road tubes or radar. Video cameras were situated to show cyclists passing over the inductive loops and to see whether the warning lights flash. In Oregon, road tube counters were used and in Colorado and Idaho, a radar unit was used to monitor traffic volume and speed near the warning signs. Video and road tube/radar data were collected before the signs were activated and while the signs were in good working order. Project goals included the following:

- Monitor system reliability in detecting bicycles in mixed traffic (where motor vehicles and bicycles share a lane).
- Assess changes in driver speed with warning system.
- Assess facility owner perceptions pertaining to the bicycle detection and warning system.
- Document installation, operation, and maintenance needs.

Video cameras were used to identify when bicycles were present and when the warning lights flashed to monitor system reliability. A radar unit or road tubes were used to monitor motor vehicle speeds before and after system installation.

Staff from the Western Transportation Institute (WTI) at Montana State University documented the installation process and led focus group discussions with road operators and agency staff familiar with the warning systems. A questionnaire was used to guide the focus groups to gather information on system operation and maintenance needs and facility owner perceptions of the systems.

Site visits were conducted to meet partners, select locations, discuss project details, and seek public input. Implementation plans were completed for each site that documented plans, proposed schedules, and responsibilities for system deployment and monitoring.

Project results will be useful to jurisdictions that oversee rural roads where high speeds, road geometry, or other factors make people on bikes particularly vulnerable. It will provide federal land management agencies (FLMAs), state departments of transportation (DOTs), local agencies, and tribes with guidance to implement bicycle detection technologies with warning systems.

This work was conducted under the Coordinated Technology Implementation Program (CTIP) administered by the Federal Highway Administration. Funding was provided by CTIP and the Accelerated Innovation Deployment (AID) Demonstration Project through the U.S. Fish and Wildlife Service. WTI staff conducted the work in partnership with staff at Colorado National Monument, Oregon Department of Transportation, and Boundary County, Idaho.

2.1. Site Selection and Requirements

The sites selected for dynamic warning system deployment were based on the following criteria:

- rural roads that are popular bicycle routes,
- mixed traffic roads that have narrow lanes and lack shoulders, where people on bikes and in motor vehicles must share the lane,
- road operators are interested and show support for piloting dynamic warning systems, and
- roads are in or near federal lands.

The two Colorado warning signs are located on a National Park Service road. The two Oregon signs are located on an Oregon State Highway that passes through Forest Service lands. The two Idaho signs are located on a county road that connects a rural community to a National Wildlife Refuge.

The following Eco-Counter guidance was used to locate their Zelt inductive loops for mixed traffic roads where bicycles and motor vehicles share a lane.

1. Choose a section of road that has uphill travel or a flat section, where there is likely a greater speed differential between bicycles and motor vehicles.
2. Avoid areas subject to electromagnetic interferences such as:
    - Electrical wires, overhead or underground
    - Buried telecommunications equipment, etc.
3. Avoid locations where circulation is congested such as:
    - Peaks of inclined paths
    - Places where motor vehicles or bicycles tend to stop
    - Proximity to road crossings
    - Proximity to lookout points
    - The presence of undesired obstacles through the area being counted

In addition to Eco-Counter guidance, WTI staff worked with road operators in these various jurisdictions to understand their needs and determine dynamic warning system requirements specific to their location. The dynamic warning systems consist of two main components:

1. Solar powered flashing light system, signpost, and bicycle ahead signage
2. Eco-Counter's Zelt inductive loop bicycle detection system

In all three states, the Eco-Counter Zelt inductive loop system was used for bicycle detection. However, two different flashing light systems were used. In Colorado, a TAPCO brand flashing light system was used that has eight LED lights integrated into the edge of the bicycle sign panel. In Oregon and Idaho, a JSF Technologies brand flashing light system was used consisting of dual amber flashing beacons, one above and one below the bicycle ahead signage. Site selection and dynamic warning equipment requirements are described in more detail for each location in the following sections.

2.1.1. Colorado Warning Sign Location and Equipment

Colorado National Monument (COLM) managed by the National Park Service (NPS) is approximately six miles from Grand Junction, Colorado. It has a long history of bicycle use on Rim Rock Drive and conflicts between motorists and bicyclists pose ongoing safety issues. The road is narrow with two 10 feet wide lanes with little to no shoulder and has hairpin turns that lack the sight lines needed for safe passing of bicycles. Average daily traffic (ADT) was approximately 640 vehicles per day in the westbound travel lane during the study period. ADT for both the east and westbound lanes was approximately 1400 vehicles per day. . The speed limit is 25 miles per hour on this section of road. Rim Rock Drive often has large recreational vehicles 40 feet in length, semi-tractor trailers, tour buses, and dump trucks which have difficulty staying in their lane. In addition, this road is used regularly by people commuting from Glade Park, an unincorporated town with about 2,000 residents to and from Grand Junction. During the summer months, bicycles can account for up to 10% of the vehicles on the east hill of the monument.

Figure 1: Colorado National Monument warning sign 1 with bicycle blinker panel (photo: WTI)

One warning system was placed in the westbound lane of Rim Rock Drive, 0.7 miles from the east entrance station. This location is just before the first hairpin turn and was selected to warn drivers of bicyclists ahead where the road is curvy with blind corners and short sight distances. The second sign was placed further up the east hill near the south entrance to the tunnel, 2.4 miles from the east entrance station. This location was selected to warn drivers of bicyclists ahead in the tunnel and curvy sections of road beyond. Both systems were installed for traffic heading west (uphill), because the inductive loop detection is more accurate when there is a speed differential between bicycles and motor vehicles. Both locations receive ample sun for the solar panels. This section of road has a substantial amount of commuter traffic that travels between Glade Park and Grand Junction and is a popular cycling route. The speed limit is 25 miles per hour.

Two different flashing light systems were considered: dual amber flashing beacons and a blinker panel with eight LED lights integrated into the panel border. To address possible light pollution and choose the most streamlined option for this sensitive NPS setting and for consistency with the NPS night skies initiative, the blinker panel sign was selected. Both options are allowable per the Manual on Uniform Traffic Control Devices (MUTCD), however, the blinker sign was determined to be a better option for reducing light pollution, should the system be triggered at night. Brown signposts were selected for consistency with other signage in the area. Rather than the standard 4-inch wood post typically used in the park, a metal post was selected. The inductive loop wiring fits inside the metal post and a standard cap fits with the solar panel on top of the sign, resulting in a waterproof system. This eliminates the need for extra conduit to cover wiring on a wood post. The metal post was powder coated for durability. The warning sign system included the following components:

- Tapco W11-1 bicycle blinker sign panel, 30 inches, solar powered, 13 Watts
- Controller, bike detector ready, with 35 Amp hour battery
- 30 Watt/ 12 Volt Solar Package
- W16-9p Ahead Sign panel, 24 inches x 12 inches
- 4.5 inch outside diameter, 13 ft long steel post

The original order had a 2-inch diameter square steel pole kit with post, anchor & bracket. Upon delivery it was realized the larger diameter post was needed, thus it was replaced with a 4.5-inch diameter post. The equipment costs were approximately $7600 each for a total of $15,200 for these two dynamic warning systems. This cost does not include foundation materials or installation. The control panel for this system can be accessed by a person standing on the ground, making it easy to access for maintenance and setting adjustments. This also makes it easier to access for vandalism, though none was reported during this pilot.

2.1.2. Oregon Warning Sign Location and Equipment

The McKenzie Pass Scenic Bikeway, located on Oregon State Highway 242 near Sisters, Oregon, is part of the Trans America bike route and is a popular route for cyclists. This rural road is narrow and has 2- lanes that lack shoulders. It has many curves with limited sight distance and there are concerns for the safety of people on bicycles, who must share the lane with motor vehicles. Average daily traffic (ADT) was approximately 280 vehicles per day in the westbound travel lane during the study period. ADT for both the east and westbound lanes was approximately 560 vehicles per day. Generally, the speed limit on rural highways in Oregon is 55 miles per hour. ODOT's sign inventory for this section of road does not contain any regular speed limit signs, though it does show a 30 mph curve warning sign in the westbound lane, near milepost 78.78 and a 20 mph curve warning after MP 84.76. This scenic road is operated by the Oregon Department of Transportation (ODOT) and runs through the Deschutes and Willamette National Forests.

One dynamic warning system was placed approximately seven miles west of Sisters at McGregor's curve (near ODOT mile post 84.76) and the other is approximately 13 miles west of Sisters (near ODOT mile post 78.78). For brevity, these will be referred to throughout this document as MP 78 and MP 84. Both systems were installed on the east side of McKenzie Pass and are visible for traffic heading in the westbound direction (uphill) from Sisters. These locations were selected for the following reasons:

- There is a lot more uphill, westbound bicycle traffic on the east side of the Pass which offers a better opportunity to test the dynamic warning system's usefulness.
- There were more obvious sign locations on the east side of the Pass because the curvy sections are very pronounced relative to the non-curvy sections. Conversely, the west side of the Pass is very curvy the entire way, which makes it more difficult to say one location is better than another.
- The east side of the pass receives significantly less precipitation than the west and the signs were located to maximize solar exposure.
- Signs were located so they did not interfere with scenic views of the lava fields.

Figure 2 shows the warning sign approximately seven miles west of Sisters, Oregon, with the concrete pull box and inductive loops in the foreground.

Figure 2: Hwy 242 warning sign near Milepost 84 with dual amber beacons near Sisters, Oregon (photo: WTI)

A dual amber beacon system was selected for the Oregon sites. Based on experience with amber beacon systems, ODOT preferred beacons (rather than a bicycle sign panel with lights integrated into the panel) for its durability and consistency with other ODOT signs.

This JSF Technologies Activated Flashing Beacon system includes:

- Solar powered beacon (JSF Technologies model AB-7412), vertically mounted
- 12-inch diameter round beacons with backplates, controller tip out to connect to loop via dry contact closure

- WP5 Flash Controller Modification for four-minute timing interval
- 4-inch diameter x 15 feet long steel poles, powder coated

- Powder coated frangible bases with collars, anchors, washers, and nuts

ODOT provided the bicycle ahead sign panels per the following specifications:

- W11-1 Bicycle sign 36” x 36”
- W11-9P Ahead sign 30” x 18”
- HDO plywood – ¾ inch thick
- ASTM Type III sheeting

In rural areas with a history of gunshot vandalism, HDO plywood substrate should be considered because unlike aluminum, the plywood can often sustain gunshot damage and remain readable. HDO plywood is very rigid and is an excellent substrate for signs that must withstand a lot of wind pressure. This substrate should be used in Snow Zone areas because it holds up very well against the snow blower and snowplow damage.

ASTM Type III Sheeting is also known as High Intensity. On State Highways, this is the minimum reflective sheeting allowed and the most used sheeting. Almost all ground mounted signs will use Type III sheeting for backgrounds and almost all legends. This sheeting is warranted for 10 years from the manufacturer.

The equipment cost for the dynamic warning systems in Oregon was approximately $9600 each for a total of $19,200 for the two systems. This cost does not include concrete, rebar and foundation materials, which were supplied by ODOT. It also does not include installation.

2.1.3. Idaho Warning Sign Location and Equipment

The Kootenai National Wildlife Refuge is in Boundary County Idaho, approximately five miles west of Bonners Ferry. Access to the refuge is via Riverside Road, a paved, narrow, two lane road (22 feet wide). Average daily traffic (ADT) was approximately 220 vehicles per day in the westbound travel lane during the study period. ADT for both the east and westbound lanes was approximately 440 vehicles per day. The speed limit is 25 miles per hour on this section of road. Riverside Road is generally flat and relatively straight, though a notable exception is around Ambush Rock where the road has tight corners and is constrained by rock outcrops. This road is used by large farm equipment and haul trucks. Eagle Point Quarry is near the Ambush Rock area and Riverside Road is a principal route to USDA Forest Service land with active timber harvest. In addition to the motor vehicle traffic, it has frequent use by people on bicycles. The refuge and swimming accesses on the Kootenay River are popular destinations from Bonners Ferry that are accessed by Riverside Road. Refuge staff, Boundary County officials, and other residents have all expressed concern regarding the potential conflicts between users of Riverside Road.

Two dynamic warning systems were installed on Riverside Road: one on the east side of Ambush Rock, viewable by westbound drivers heading out of town. The other sign is on the west side of Ambush Rock, viewable by eastbound drivers heading into town as shown in Figure 3. This section of road was selected because of the limited site distance and constrained road conditions imposed by rock outcroppings.

Figure 3: Riverside Road (west) warning sign, Boundary County, Idaho (photo: WTI)

The JSF dual amber beacon system was selected for the Idaho sites. The dual amber flashing lights were thought to be more visible during daylight hours when most bicycles are present. The details of how the components fit together was better understood based on the previous experience deploying the Oregon systems. This JSF Technologies Activated Beacon System includes:

- Top of pole mounted cabinets with two AGM 12-Volt 18-Amp hour batteries, wireless radio, flash controller, dry contact closure for Zelt Sensor and integrated 40-Watt solar panel.
- Controller modification for 1–5-minute intervals
- Two 12-inch round LEDs with louvered poly backplates
- 4-inch diameter x 15 feet long powder coated steel poles
- Powder coated aluminum frangible bases with anchors, washers, and nuts
- 30-inch x 30-inch W11-1 bicycle sign panels with mounting hardware, black/yellow
- 24-inch x 12-inch W16-9P ahead sign panels with mounting hardware, black/yellow

Concrete, rebar and foundations were supplied and installed by Boundary County. The standard flash controller needed modification by the manufacturer to allow the flashing light length to be set for 1-to-5-minute increments.

2.2. Installation Process

Public meetings were conducted in Grand Junction and Fruita, Colorado in spring 2017 and in Bonners Ferry, Idaho in August 2018 to provide information about the pilot projects and to seek public input. WTI met with ODOT and USFS staff in September 2018 to discuss the project and select locations, though no public meeting was conducted. Once environmental clearance was secured by each jurisdiction, the systems were installed as described below.

2.2.1. Colorado Warning Sign Installation

In May 2018, two warning signs were installed on Rim Rock Drive as part of a roadway project funded by the Federal Lands Access Program (FLAP). The concrete bases were poured ahead of time off site. Then the concrete bases, signposts, solar and bicycle blinker and ahead panels were installed on-site. A Rainbird irrigation container was installed about 20 feet before the sign to contain the Eco-Counter data loggers and batteries. A two-foot-deep trench was dug to contain the 2-inch diameter conduit for the wiring between the signpost and manhole. The inductive loops were located approximately 20 feet before the sign, to allow cyclists to trigger the lights prior to reaching the sign and enable them to view the flashing lights.

Figure 4: Contractor installing inductive loops for bicycle detection at Colorado National Monument (photo: WTI)

In early June 2018, WTI staff met a Grand Junction area contractor on-site to oversee the pavement saw cuts and inductive loop installation as shown in Figure 4. While this contractor had installed inductive loops to detect motor vehicles, they had not installed loops to detect bicycles. There is a specific method for the sawcut and inductive loop configuration that is required for the system to function properly for bicycle detection. Eco-Counter provides training on this method to ensure proper installation. These saw cuts were approximately 3/8 inches wide and two inches deep near the road centerline and two and a half inches deep near the edge of the road to enable to wires from the loops near the centerline to connect to the counter. Loop wires were tightly wrapped, and inductance tests showed 130 and 150 microhenries, which confirmed proper functioning prior to sealing.

The saw cuts for the first sign took about two hours to complete and another hour to lay the wires for the loops and seal them. The wires were covered with backer rod (round, flexible lengths of foam that are used as a “backing” in joints or cracks) to insulate them from the epoxy and prevent them from floating up. The Eco-Counter data loggers and batteries were placed in the Rainbird irrigation box and connected to the loops and flashing light sign system.

There are four settings for the blinker sign: continuous 24-hour flashing, time clock activation, wireless control activation or vehicle detection activation. For this case where the sign is activated by a bicycle, the vehicle detection setting was selected. These signs were set to flash for three minutes each time a bicycle is detected. Some modifications were made to connect the sign and bicycle counter. These systems use rechargeable batteries from Eco-Counter that connect to the solar panel for the warning sign, rather than batteries that require replacement every year or two. This solar panel is deemed sufficient to charge both the battery for the flashing lights as well as the bicycle counter. Thus, in addition to the wires connecting the sign to the counter, a power wire was added between the solar panel and the counter, to charge the batteries. Figure 5 shows the wiring diagram to connect the Zelt system to the Tapco sign.

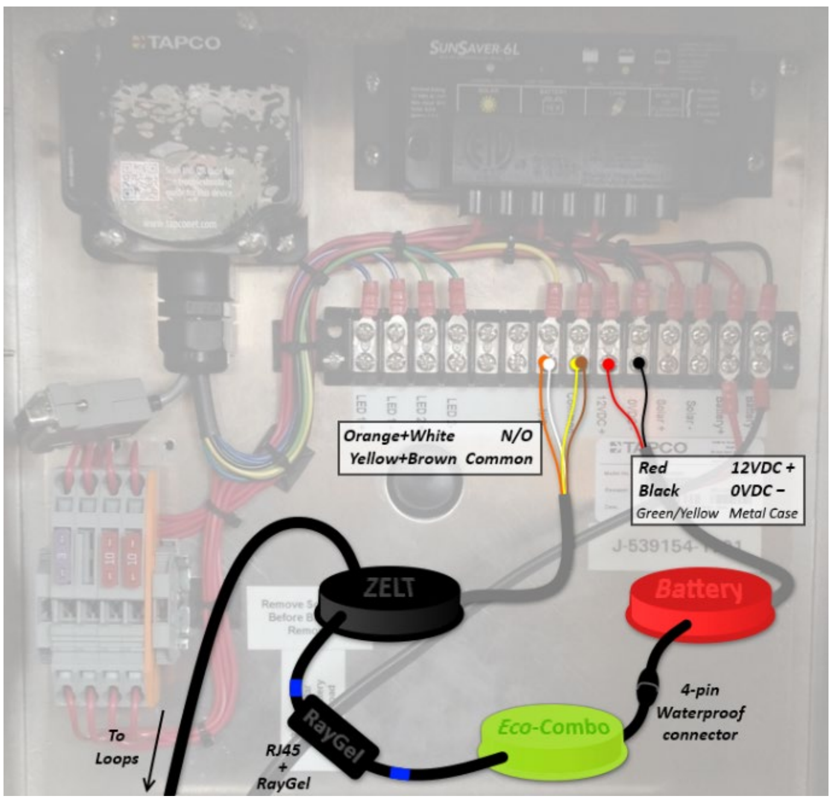

Figure 5: Eco-Counter to Tapco blinker sign wiring diagram (Courtesy Eco-Counter)

WTI staff used a Bluetooth enabled laptop on-site and spoke with Eco-Counter technical staff for guidance on initiating and testing the system. A bicycle and a motor vehicle traveled over the loops several times to test that the lights flashed as intended, only when a bicycle crossed the loops. The first warning system took roughly eight hours for loop and Eco-Counter installation, connecting to sign, programming, and testing the system.

The next day, the same process was repeated for the second sign system, which only took three hours to perform saw cuts, install loops, connect to flashing lights, program, and test the system. The contractor learned the finer details of bicycle loop counters the first day and the process went much quicker the second day. The location of the first sign had poor cell reception, thus the bicycle counter automatic data transmission option (purchased for the first year), did not always function at this site.

2.2.2. Oregon Warning Sign Installation

In May 2019, the ODOT Region 4 electrical crew assembled sign components in their Bend, Oregon shop. They installed the concrete sign foundations and concrete pull boxes on-site. The pull boxes protect the Eco-Counter data logger and battery from vehicles that may pull onto the soft shoulder and are more durable than the plastic Rainbird irrigation box typically used. The concrete requires about a week to cure prior to installing the signposts.

Figure 6: Oregon HWY 242 dynamic warning sign near Milepost 78 and concrete junction box (photo: ODOT)

Figure 5 shows the upper warning sign near milepost 78.78 with the concrete pull box in the foreground. A 2 feet deep trench was dug to contain the 2-inch conduit that holds the wires between the data logger and warning sign.

In early June 2019, ODOT hired a subcontractor to sawcut the pavement and install the Zelt inductive loop system per Eco-Counter guidance.

ODOT hauled the signs on a trailer to the site and used a truck with a crane to lift the sign system into place and install into the foundation. A second truck with an extended bucket allowed an electrician to access the electric panel located at the top of sign, about 12 feet above ground. The higher elevation section of Hwy 242 over McKenzie Pass is closed to motor vehicles during the snowy season typically from October through mid-June. Part of the warning system installation occurred prior to the road opening on June 17, 2019, reducing the need for traffic control.

On June 25, 2019, the warning signs were connected to the bicycle detection systems. Both systems activated the flashing lights for four minutes as intended, when bicycle traffic crossed the loops. However, the JSF flash controller did not reset the 4-minute timer with each bicycle activation. Also, the flashing lights were being activated every 15-minutes, even without any traffic. After some troubleshooting, it was discovered that the bicycle data logger was triggering the flashing light system every 15 minutes, which is the time interval that the bicycle count data is binned. This can be fixed if the flashing light system can be adjusted to ignore small contact pulses. The JSF system did not appear to have this option, so a separate device called a Connex board (provided by Eco-Counter) was required. On July 22, 2019, the ODOT crew installed the Connex boards and tested the systems to ensure the flashing lights were working as intended. Figure 6 shows the wiring connections between the Connex board (green square) and JSF sign. A Connex board wiring diagram from Eco-Counter can be found in Appendix A.

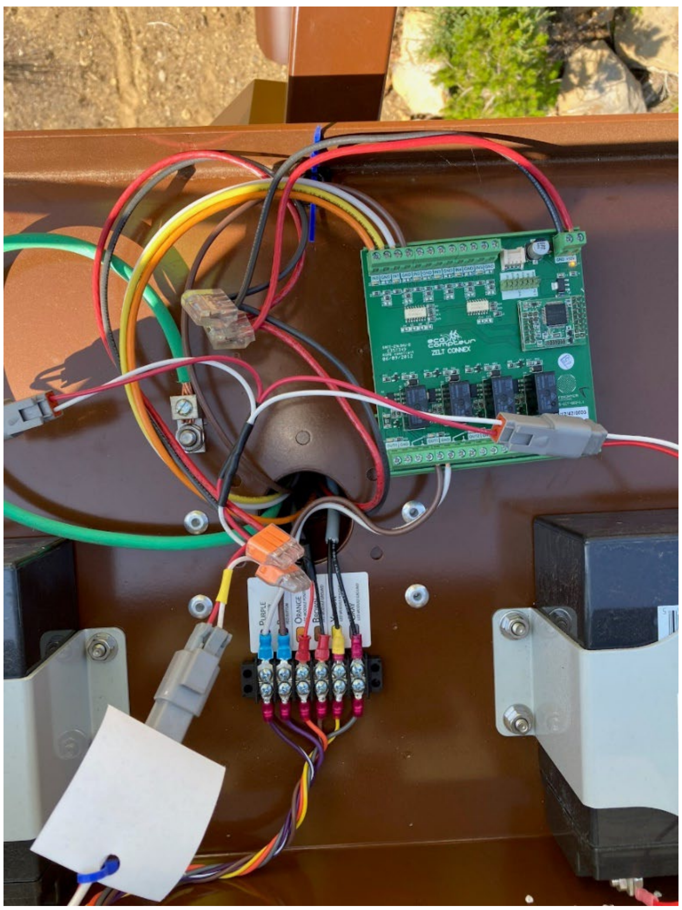

Figure 7: Wires connecting JSF sign controller and Eco-Counter Connex board (photo: ODOT)

The ODOT electric crew had some recommendations to improve the installation. The first is to use inductive loop wire that has a higher heat rating. The loop wire used was rated for 140 degrees F, though the salient heats up to 300 degrees. Thus, a concrete epoxy was used, to not melt the loop wire.

Figuring out why the sign flashed every 15 minutes required significant time and research. For future applications, ODOT staff recommends working with the manufacturer more closely to work out the bugs before installation.

The JSF system has limitations on the timing for flashers. They could only be set for four minutes, then 10 minutes, with no settings in between. Working with the manufacturer to set the site-specific requirements is recommended.

Lastly, ODOT had a few recommendations for the design of the junction box that holds the bicycle counter and batteries. ODOT's junction box design includes a concrete apron that has gravel underneath, which helps keeps the system clean and dry. In addition, using concrete is more durable than the Rainbird plastic irrigation box typically used to house the counter. Along with the concrete junction box and apron, ODOT installed sand pockets where the loop wires come out at the edge of the road pavement. The sand pocket helps protect the wires from vehicles that may leave the pavement as well as keeping the wires clean and dry. ODOT's junction box (TM 472), sand pocket (DET428 with photo) and pedestal/foundation specifications (DET4431) may serve as good examples and are included in Appendix A.

2.2.3. Idaho Warning Sign Installation

In late September 2019, Boundary County staff rented a pavement saw cutter and installed the inductive loops and Eco-Counter data logger for their sign east of Ambush Rock. WTI staff initiated and tested the Eco-Counter system and set up the video and radar unit for the "before" monitoring. The signpost/flashing light systems were not installed at this time.

Figure 8: Riverside Road (east) warning sign, Boundary County, Idaho (photo: Boundary County)

In early June 2020, Boundary County staff installed the east and west sign/flashing lights on Riverside Road. They had to bring in fill because the road slope dropped off and there was no space to install the sign foundation. After the fill was in place, it was realized that the eastern sign was directly under some overhead wires. Utility company staff visited the site, and it was determined that if the post was cut 2-3 feet, there would be enough space between the top of the sign and the wires to keep the sign in this location. The post was cut and installed as shown in Figure 8. The foundation was poured on site and after a week, the signpost, panels, solar, and flashing light systems were installed. County staff also sawcut and installed the loops for the west sign in early June 2020.

WTI staff then arrived and helped initiate the Eco-Counter and test the two systems. Boundary County staff set the signs to flash for three minutes. These two Idaho warning signs use the same JSF technologies sign system as the Oregon signs. Based on previous experience with Oregon warning signs, Connex boards were ordered ahead of time for these systems and the controller was programmed by JSF to include flash durations specific to this location, ranging from 1-6 minutes as shown in Figure 9. However, the process to install the Connex boards and connect the sign to the bicycle counter was still challenging and took quite a bit of time. Figure 10 shows the Boundary County Road crew working on the JSF control panel, for the west sign. Notice a bucket truck provides access to the control box which is integrated with the solar panel at the top of the sign. After installation, it was realized the Eco-Counter was not working properly. Boundary County staff worked with Eco-Counter and were able to replace some damaged parts in a timely manner, after which the system functioned properly. Figure 11 shows the inside of the JSF control box. Notice the green Connex board in the front of the box, which has not yet been connected in this photo.

Figure 9: JSF control panel dials for the Idaho warning systems (photo: Boundary County)

Figure 10: Boundary County crew working on Riverside Road (west) sign (photo: Boundary County)

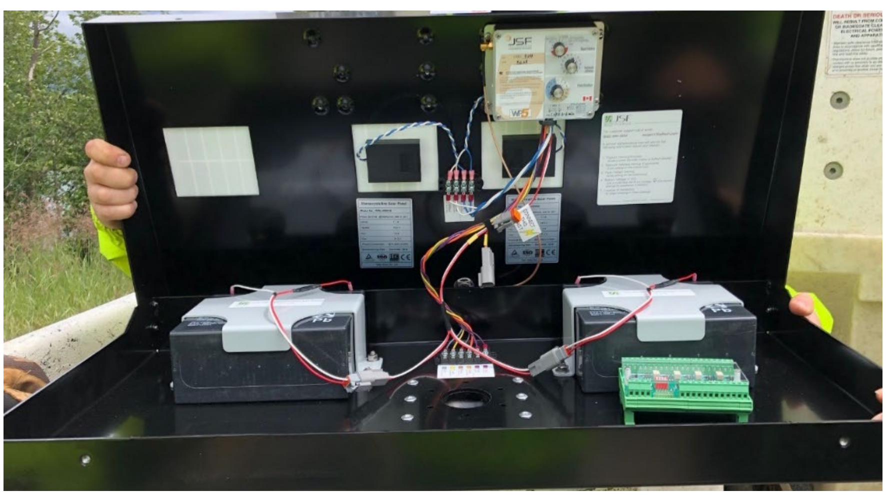

Figure 11: JSF solar and control box (photo: Boundary County)

2.3. Monitoring and Analysis

Monitoring consisted of video cameras and road tubes or radar to collect motor vehicle speed and volume data. Video cameras were set up in a discreet place, typically attached to a tree, where they were unlikely to be seen by people passing by on bike or motor vehicles. Video cameras were situated to show motor vehicles and cyclists passing over the inductive loops and to indicate whether the warning lights flash. Video was not of sufficient quality to read license plates to address privacy concerns. In Oregon, road tube counters were used and in Colorado and Idaho, a radar unit was used to monitor traffic volume and speed near the warning signs.

The following sections describe the process for monitoring warning sign reliability, assessing changes in driver speed, and evaluating facility owner perceptions on the systems. The warning systems at Colorado National Monument are described first, followed by the Hwy 242 systems in Oregon, and the Boundary County, Idaho systems. Every time the Eco-Counter registers a detection, whether it be a bicycle or the occasional motor vehicle, the lights flash. Thus, for all of the warning signs, the reliability depends on the Eco-Counter inductive loops within the pavement identifying a bicycle, rather than the counter's connection to the flashing lights.

2.3.1. Colorado Warning Sign Reliability

Daylight video collected over 31 days (June 6, 2018, through August 1, 2018) was reviewed and compared to the Eco-Counter data to assess the reliability of the Colorado Sign 1 warning sign. Video data was not available from June 15 through 27 and from July 14 through 24, 2018, due to battery and data storage issues. Warning Sign 1 is in the westbound lane of Rim Rock Drive, 0.7 miles from the east entrance station in Colorado National Monument.

Warning Sign 2, also on Rim Rock Drive, 2.4 miles from the east entrance station had limited usable data due to glare from the sun. On most days, after about 7:00 am, it was not possible to discern on the video whether the sign's blinker lights were flashing. After much scrutiny, it was determined that Sign 2 data was of insufficient quality to perform a meaningful analysis. These two warning systems were identical in design, thus what may be learned from the analysis of Sign 1 may inform decisions for both warning systems.

Video footage was reviewed and compared to the Eco-Counter data to determine the warning system reliability. Considering the safety for people riding bicycles, the following items were assessed:

- Correct detections – the system activates when a bicycle passes over the Eco-Counter inductive loops.
- False positives (misidentifications) – the system activates when there is no bicycle present.
- False negatives – the system does not activate when a bicycle passes over the Eco-Counter inductive loops.

From June 6 through August 1, 2018 (after the sign was installed), 733 bikes were observed near Warning Sign 1 on the video (the "true" value) while the Eco-Counter recorded 706 detections. Of the 706 Eco-Counter detections, review of the video showed 76 of them were motor vehicles (false positives). After subtracting out the false positives, 630 bikes (the "observed value") were detected by the Eco-Counter. The bicycle detection error rate of the Eco-Counter can be estimated by taking the difference between the "observed value" and the "true value" in comparison to the "true value" and multiplying by 100 to express as a percentage, as summarized in the following formula.

Percent error = (observed value – true value)/ true value X 100

= (630 – 733)/733 X 100

= - 14.1%

Table 1 shows the parameters used for the Colorado Sign 1 reliability estimates.

Table 1: Colorado Sign 1 Reliability Estimate Parameters and Results

Parameter	Description	Value
Bikes present	Bicycles identified by video review (true value)	733
All Detections	Total Eco-Counter detections (correct and false positives)	706
Correct detections	Bicycles correctly detected by the Eco-Counter ("observed value" for percent error)	630
False positives	The warning sign lights flash when there is no bicycle present.	76 → 10.8 % of 706
False negatives	When a bicycle crosses the Eco-Counter loops, but is not detected	103→ 14.1% of 733
Percent Error	Warning system bicycle detection percent error (630 – 733)/733 X 100	-14.1 % undercount

Out of 733 bikes identified by video review, the system correctly detected a bike passing over the Eco-Counter loops 630 times. This approach estimates the warning system's bicycle detection percent error at -14.1%. In other words, the system undercounted bicycles by 14.1 percent. Thus, the system correctly detected bicycles 85.9% of the time.

False positives- Among the 706 total detections, there were 76 occasions when a motor vehicle was detected by the counter, triggering the lights when there were no bikes present. Thus, the system mis-identified a motor vehicle as a bike on 76 of the 706 counter detections or 10.8% of the detections. Typically, the false positives were pickup trucks and vehicles with trailers. Occasionally, the warning sign was triggered by a car, tractor-trailer, single-unit truck or motorcycle. Fifteen of these were vehicles in the opposing lane, heading east. Some reasons for misidentification could include:

- Trailers and pickup beds inducing a current after the vehicle was expected to have passed. Thus, the sensor may mis-identify a trailer as a bicycle close behind a motor vehicle.
- Opposing lane vehicles could have induced currents similar to bicycles
- Motorcycles can induce currents similar to ferrous bicycles
- Vehicles stopping over the sensor

False negatives- The system missed detecting 103 of the 733 bicycles observed on video, or 14.1 percent of the bicycles observed. Group riding was common at Colorado National Monument with almost 100 groups of two or more cyclists observed during the study period. While the counter sometimes missed detection of one or two bikes when people rode in groups, there were only four cases when people rode in groups that the lights did not flash at all. Each of these four cases consisted of a group of two bikes. Other reasons for the counter not detecting bicycles (false negatives) could include:

- The bicycles not passing directly over the induction loops. Bikes may not be detected when riding over the outside edge of the loops, or through the three-inch gap between the loops.
- The bicycle was not of standard configuration, such as a tandem bike. Though there were only a few tandem bicycles observed, not all were detected.
- The bicycle was not of expected ferrous composition. It was not possible to determine the material composition of all the bicycles observed, though carbon fiber bicycles are common.

2.3.2. Colorado Warning Sign Speed Analysis

This section compares motor vehicle speeds before and after the dynamic warning system installation. The speed limit is 25 miles per hour on Rim Rock Drive in the vicinity of the warning signs. Motor vehicle data from the radar, including the speed and timestamp for each motor vehicle were delineated into four groups.

1. **Before Sign Bicycles Present group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no more than 30 seconds before a bicycle passes by the site and up four minutes after a bicycle passes by the site. This timeframe is intended to include drivers whose behavior may be influenced by the presence bicycle on the roadway in the vicinity of the warning sign.
2. **Before Sign Bicycles Absent group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike passed the site. This timeframe is intended to ensure that driver behavior is not influenced by the presence of a person on a bicycle. If a person is cycling at a speed of seven miles per hour, they would be at least a half mile away from a vehicle that arrives at the warning sign five minutes later. On Rim Rock Drive,

the lights were set to flash for three minutes, and therefore would be off for a full two minutes if a motor vehicle arrives five minutes after a bike.

3. **After Sign Bicycles Present group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no more than 30 seconds before a bicycle passes by the site and up four minutes after a bicycle passes by the site.
4. **After Sign Bicycles Absent group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike passed the site.

Motor vehicles that arrived at the warning sign sites within five minutes of a bicycle, but that fall outside of the bicycle present groups, were omitted from the analysis. It is not clear if these drivers would be influenced or not by bicyclists, therefore they were omitted to avoid mis-categorizing them. The section below discusses Colorado Sign 1, in the westbound lane of Rim Rock Drive, 0.7 miles from the east entrance station in Colorado National Monument. This sign detects bicycles in the westbound lane, where there is typically a greater speed differential between bikes and motor vehicles due to the uphill topography for westbound travel. The first part provides a visualization and exploratory data analysis of the raw speed data from the radar. The second part uses a mixed effect model to assess if changes in motor vehicle speed before and after the warning system differed by bicycle presence while accounting for day-to-day speed variation.

Colorado Warning Sign 1 Raw Speed Data Visualization and Analysis

Near Colorado Sign 1, before the warning sign was installed, 247 bicycles were observed in the westbound lane over eight days from May 3-10, 2017. After the sign was installed, 733 westbound bicycles were observed over 31 days between June 6 and August 1, 2018. Video data was not available from June 15 through 27 and from July 14 through 24, 2018, due to battery and data storage issues. Data was limited to daylight hours between 6:00 am and 7:30 pm.

Of the 3830 vehicles in the Before Sign groups, 554 vehicles were omitted because they were within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 3276 vehicles. Of the 16,272 vehicles in the After Sign groups, 1123 vehicles were omitted because they were within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 15,149 vehicles. Table 2 summarizes the Colorado Site 1 data groups.

Table 2: Colorado Sign 1 Before and After Bicycles Present/Absent Groups

Group	Motor Vehicles	Total vehicles in Before-Sign and After-Sign Groups
Before Sign Bikes Present	526	3276
Before Sign Bikes Absent	2750	
After Sign Bikes Present	1239	15,149
After Sign Bikes Absent	13,910	

Figures 12 and 13 show radar speeds near Colorado Site 1 in miles per hour (mph). Figure 12 shows speeds for Before-Sign/Bikes Present and Before-Sign/Bikes Absent groups. Figure 13 shows speeds for After-Sign/Bikes Present and After-Sign/Bikes Absent groups. The yellow dots represent vehicle speed for the Bikes-Present groups and the blue dots represent vehicle speed for the Bikes Absent groups.

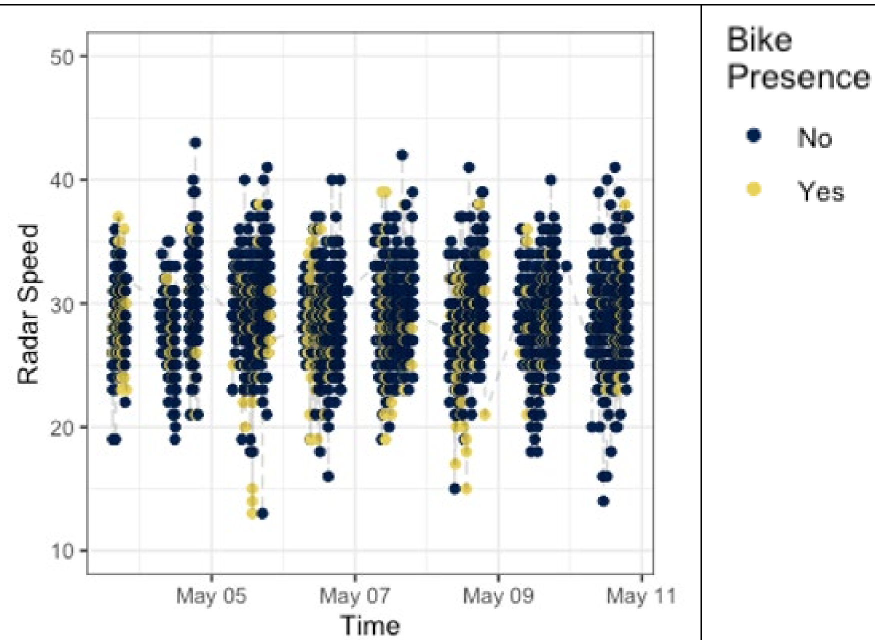

Figure 12: Colorado Sign 1 vehicle speeds before warning sign

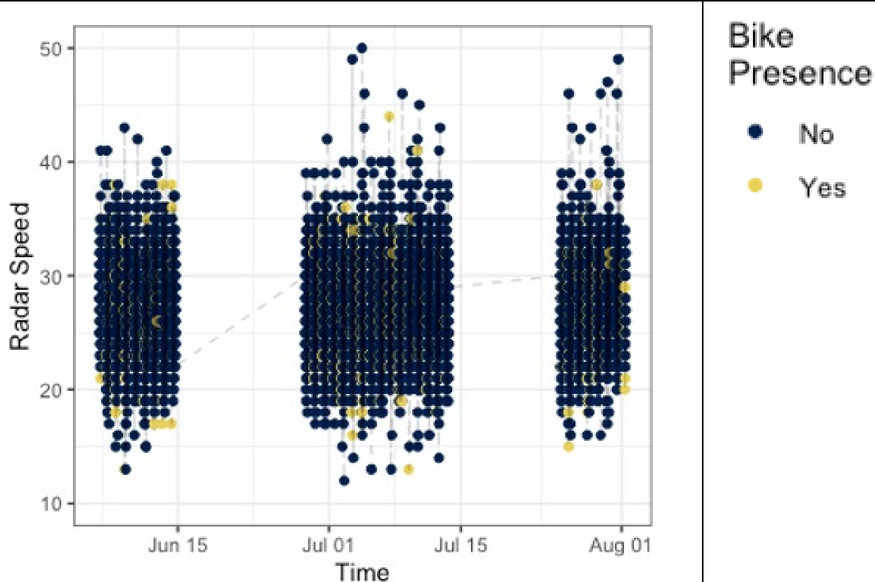

Figure 13: Colorado Sign 1 vehicle speeds after warning sign

Table 3 shows vehicle speeds in miles per hour (mph) for the bikes present group. The mean speed, median, and 85th percentile speeds decreased after the warning sign was installed by 1.37 mph, 2 mph and 2 mph respectively.

Table 3: Colorado Sign 1 Bicycles Present: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	526	28.41	3.62	13	29	39	32
After	1239	27.04	3.52	13	27	44	30
Difference		1.37			2		2

Table 4 shows vehicle speeds for the bicycles absent group. The mean speed, median, and 85th percentile speeds decreased after the warning sign was installed by 1.46 mph, 1 mph, and 1 mph respectively.

Table 4: Colorado Sign 1 Bicycles Absent: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	2750	29.18	3.34	13	29	43	32
After	13910	27.72	3.38	12	28	52	31
Difference		1.46			1		1

The median speeds are similar before warning sign 29 mph (with or without bikes) but decrease after the warning sign by 1 mph and 2 mph without and with a bike respectively. Figure 14 shows vehicle speed data graphically with the 85th percentile denoted with a red dashed line.

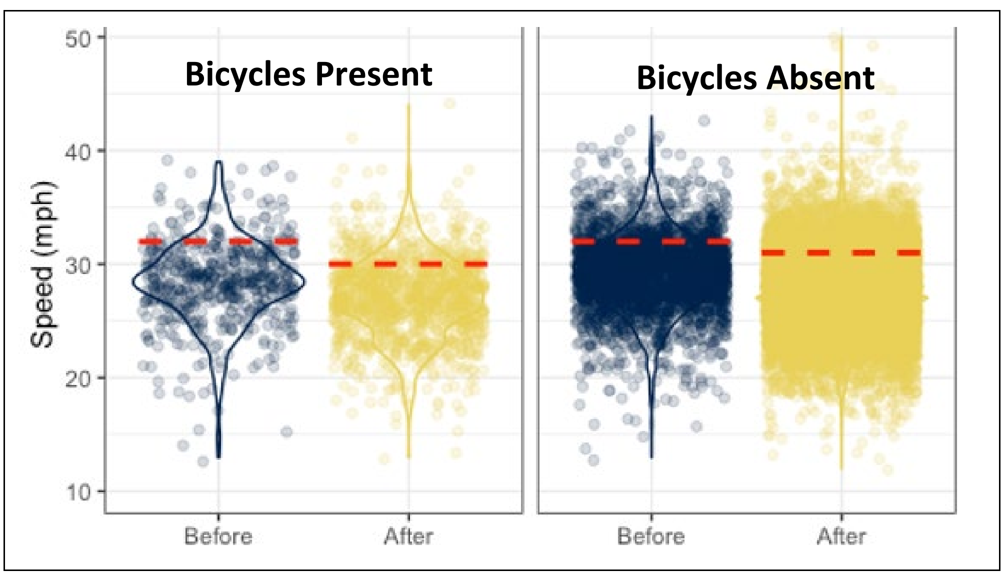

Figure 14: Colorado Sign 1 association between vehicle speed and bicycle presence/absence

Colorado Warning Sign 1 Mixed Effect Model Analysis

The previous tables and figures provided a visualization and analysis of the raw speed data. There may be variation in vehicle speeds from day to day due to activities such as road maintenance or construction, poor visibility or weather conditions, slow moving vehicles, or other factors. The following section analyzes a mixed effect model that was used to account for day-to-day speed variation. A model with an interaction of bicycle presence with before/after sign installation as the fixed effects was used to assess how the average speed differed with and without bikes present, with date used as the random intercept.

Adjusted for day-to-day variation, there is weak evidence that the average speed difference between vehicles before and after the warning sign depends on whether or not a bike was present (t = 0.445, on df = 18260 with p-value = 0.656). The p-value is a measure of the probability that the observed difference could have occurred by random chance. The lower the p-value, the greater the statistical significance or evidence of the observed difference. This model estimates a drop in mean speed of 1.37 mph when bikes were present and a drop of 1.45 mph when bikes were absent after the warning signs were installed versus before. Thus, there is a slightly smaller drop in mean speed when bikes were present as compared to when they were absent after the sign was installed (1.37-1.45 = -0.085 mph). The model shows with 95% confidence that this difference in mean vehicle speed when bikes were present versus absent ranges between a 0.289 mph decrease to an increase of 0.459 mph. These results are visualized in the effects plots shown in Figure 15. As expected, the average speed is lower after the warning sign was installed. However, the lines are relatively parallel suggesting that this relationship is similar with or without the presence of bicycles, hence there is limited interaction between the warning sign and bike presence.

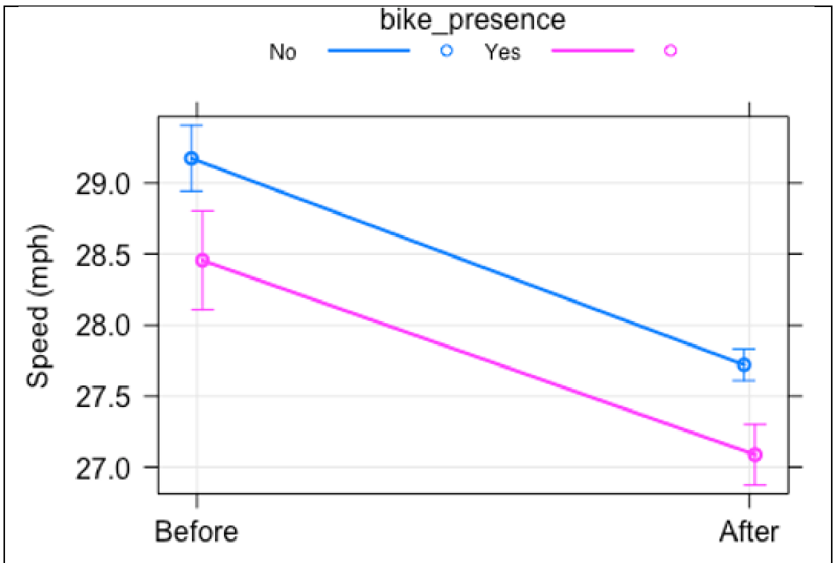

Figure 15: Colorado Sign 1 before/after warning sign and presence/absence of bikes effect on vehicle speeds

The overall explanatory power of the model is relatively modest, with only 2.70% of the variation in vehicle speed explained by the dynamic warning system, presence/absence of a bike and their interaction in the model (based on the R^2 *marginal* coefficient of determination, which describes the proportion of the variance explained by the fixed factors). Likewise, only 3.34% of the variation in vehicle speed is explained by the interaction between the dynamic warning system and presence/absence of bikes, their marginal effects, and day-to-day variability in the model (based upon the R^2 *conditional* coefficient of determination, which describes the proportion of variance explained by both the fixed and random factors).

Next, four inquiries were tested as described below, controlling for day-to-day variation, with results shown in Table 5, where H_0 is the null hypothesis and μ is the mean vehicle speed.

Inquiry 1) *H_0: μ Before Sign Bikes Present – μ After Sign Bikes Present = 0*

When bicycles are present, the difference in mean vehicle speeds before minus after the warning sign was introduced equals zero.

Inquiry 2) *H_0: μ Before Sign Bikes Absent – μ After Sign Bikes Absent = 0*

When bicycles are absent, the difference in mean vehicle speed before minus after the warning sign was introduced equals zero.

Inquiry 3) *H_0: μ Before Sign Bikes Present – μ Before Sign Bikes Absent = 0*

Before the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when bikes were absent equals zero.

Inquiry 4) *H_0: μ After Sign/Bikes Present – μ After Sign/Bikes Absent = 0*

After the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when absent equals zero.

Table 5 summarizes the evidence with regard to the four inquiries described above.

Table 5: Colorado Sign 1 Inquiry Summary for Changes in Mean Vehicle Speeds

Inquiry/ Null Hypothesis H_0	**Change in mean vehicle speed μ (mph)**	**95% confidence interval (mph)**	**Two-sided p-value**
1) When bikes present, mean vehicle speed before minus after = zero	1.37 mph (slower after)	0.961 mph to 1.78 mph	< 0.0001 (strong evidence to reject H_0)
2) When bikes absent, mean vehicle speed before minus after = zero	1.45 mph (slower after)	1.2 mph to 1.71 mph	< 0.0001 (strong evidence to reject H_0)
3) Before warning sign installed, mean vehicle speed when bikes present minus absent = zero	- 0.718 mph (faster when bikes absent)	-1.04 mph to -0.401	<0.0001 (strong evidence to reject H_0)

4) After warning sign installed, mean vehicle speed when bikes present minus absent = zero	-0.633 mph (faster when bikes absent)	-0.832 mph to -0.435 mph	<0.0001 (strong evidence to reject H_0)

In terms of Inquiry 1, when there were bikes present, the estimated mean vehicle speed after the warning sign was introduced is 1.37 mph slower than the mean vehicle speed before the warning sign when controlling for day to day variation. There is strong evidence that this change differs from 0 mph with a p-value < 0.0001 and a 95% confidence interval of 0.961 mph to 1.78 mph.

In terms of Inquiry 2, when there were no bikes present, the estimated mean vehicle speed after the warning sign was introduced is 1.45 mph slower than the vehicle speed before the warning sign when controlling for day to day variation. There is strong evidence that this difference differs from 0 mph with a p-value < 0.0001 and a 95% confidence interval of 1.2 mph to 1.71 mph.

In terms of Inquiry 3, before the warning sign was introduced, the estimated mean vehicle speed when no bikes are present is 0.718 mph faster than the vehicle speed when bikes are present after controlling for day to day variation. There is strong evidence that this change differs from 0 mph with a p-value < 0.0001 and a 95% confidence interval of -1.04 mph to -0.401 mph.

In terms of Inquiry 4, after the warning sign was introduced, the estimated mean vehicle speed when no bikes are present is 0.633 mph faster than mean vehicle speed when bikes are present after controlling for day to day variation. There is strong evidence that this change differs from 0 mph with a p-value < 0.0001 and a 95% confidence interval of -0.832 mph to -0.435 mph.

In conclusion, the model suggests that there is a decrease in vehicle speed after the dynamic warning system was introduced, and this association is similar whether or not a bike is present. However, this model suggests that only a small proportion of total variability in vehicle speed (about 3.3%) may be explained by the Colorado Site 1 warning sign.

Results from this analysis can only be generalized to the population of vehicles observed over the days from 5/3/17 to 5/10/17 and 6/6/18 to 8/1/18, or vehicles similar to those that were observed. Since this is an observational study, our conclusions are based on an association between the installation of the dynamic warning sign and vehicle speed in the presence or absence of bicycles. In other words, no causal inferences can be made.

2.3.3. Colorado Warning Sign Facility Owner Perceptions

On April 30, 2021, WTI conducted an online focus group with five COLM personnel including the Chief Ranger, Planning Coordinator, Facility Manager, Maintenance Work Leader, and Fee Supervisor. A list of 19 questions was sent in advance to contacts that have worked on this project. The discussion is summarized in the five categories below.

1) Observations of bicycle/vehicle interactions

   The dynamic warning systems are in the southeast part of COLM, while most personnel work at offices in the northwest park area. Thus, most staff only travel by the warning systems about once a month and did not report observations of bike/vehicle interactions. There has been feedback from the cycling community, asking what data is being collected, is it available to the public, and how is it being used to inform management decisions. There has also been feedback from COLM workers wondering if the signs are working. They rarely see the lights flashing, so the assumption is they are not working. However, COLM workers are in cars and did not always understand that the signs only detect cyclists.

2) Installation process

The wrong sign material shipment was received (intended for Midwest location), which took some time to work out. Initially there were some difficulties with the Tapco wiring and some different mounting equipment that didn't work right. Once that was worked out, all went well. A contractor performed most of the installation and COLM staff had very little to do with the installation.

3) Maintenance and Eco-Counter function

There has not been any maintenance since the systems have been in place. COLM staff received an O&M manual with the system shipment and have experience dealing with other solar panels. This system's interface is not what they usually use, and staff might need additional technical assistance in the future.

4) Bicycle count data retrieval and online analysis/viewing

There have been a lot of staff changes at COLM since the systems were installed and there is a need for staff training on the Eco-Counter bike count data retrieval, analysis, and viewing capabilities.

5) Thoughts on system and advice for others

COLM's Chief Ranger highly recommends this system to others and commented the system is great for blind corners. Another staff received feedback from cyclists that they really appreciated the warning system when going through the tunnel. Staff changes have meant some loss in continuity for using the signs and data. The need to refresh and get up to speed has been acknowledged so new staff can make best use of the system going forward.

2.3.4. Oregon Warning Sign Reliability

Oregon site monitoring consisted of video and road tube data collected before the warning sign installation between June 17 and 24, 2019 and after the sign was installed between July 22 and August 8, 2019. There is missing video during part of this time, primarily due to battery issues. ODOT staff set up video cameras and road tubes, swapped out batteries and downloaded data.

WTI staff reviewed video footage and recorded the number of westbound bicycles and their video timestamp in an Excel spreadsheet. For the July and August video, after the warning signs were in place, staff also noted when the lights were flashing. Road tube data timestamps were adjusted to match the associated motor vehicle timestamps observed in the video. Data collection was limited to daylight hours between 6:00 am and 9:00 pm. The following sections describe analysis of the warning system reliability and vehicle speeds at Oregon MP 78 (located about 13 miles west of Sisters) and MP 84 (located about seven miles west of Sisters) before and after warning sign installations.

Daylight video collected over 18 days (July 22, 2019 through August 8, 2019) was reviewed and compared to the Eco-Counter data to assess the reliability of the two Oregon Highway 242 warning signs. Eco-Counter places detections into 15-minute bins, rather than recording each individual timestamp. Bicycles and false positives observed on the video were placed into the appropriate 15-minute bin and compared with the Eco-Counter bin data. The following sections discuss the reliability of the warning signs, beginning with the lower warning sign near MP 84.

Lower warning sign near MP 84

Video footage was reviewed and compared to the Eco-Counter data to determine the warning system reliability and the following items were assessed:

- Correct detections – the system activates when a bicycle passes over the Eco-Counter inductive loops.
- False positives (misidentifications) – the system activates when there is no bicycle present.
- False negatives – the system does not activate when a bicycle passes over the Eco-Counter inductive loops.

From July 22 through August 8, 2019 (after the sign was installed), 334 bikes were observed near MP 84 on the video (the "true value") while the Eco-Counter recorded 320 detections. Of the 320 Eco-Counter detections, review of the video showed seven of them were motor vehicles (false positives). After subtracting out the false positives, 313 bikes (the "observed value") were detected by the Eco-Counter. The bicycle detection error rate of the Eco-Counter can be estimated by taking the difference between the "observed value" and the "true value" in comparison to the "true value" and multiplying by 100 to express as a percentage, as summarized in the following formula.

Percent error = (observed value – true value)/ true value X 100

= (313 – 334)/334 X 100

= -6.3 %

Table 6 shows the parameters used for the MP 84 reliability estimates. Out of 334 bikes identified by video review, the system correctly detected a bike passing over the Eco-Counter loops 313 times. This approach estimates the systems bicycle detection percent error at -6.3 percent during the study period. In other words, the system undercounted bicycles by 6.3 percent. Therefore, the system correctly detected bicycles 93.7% of the time.

False positives- Among the 320 total detections, there were seven occasions when a motor vehicle was detected by the counter, triggering the lights when there were no bikes present. Five of these were cars and two were vans, all of which passed westbound over the Eco-Counter loops. Thus, the system mis-identified a motor vehicle as a bike on seven of the 320 counter detections or 2.2% of the detections. Over 5,000 motor vehicles crossed the loops during this time, demonstrating the system had a relatively low error rate in terms of distinguishing bicycles from motor vehicles.

Table 6: Oregon MP 84 Reliability Estimate Parameters and Results

Parameter	Description	Value
Bikes present	Bicycles identified by video review (true value)	334
All Detections	Total Eco-Counter detections (correct and false positives)	320
Correct detections	Bicycles correctly detected by the Eco-Counter ("observed value" for percent error)	313
False positives	The warning sign lights flash when there is no bicycle present.	7 → 2.2 % of 320
False negatives	When a bicycle crosses the Eco-Counter loops, but is not detected	21 → 6.3% of 334
Percent Error	Warning system bicycle detection percent error (313 – 334)/334 X 100	-6.3 % undercount

False negatives- The system missed detecting 21 of the 334 bicycles observed on video, or 6.3 percent of the time. Of these 21 false negatives, review of the video revealed that there were nine cases when people were riding in groups and the lights were flashing, even though the counter did not detect every bike in the group. In the other 12 cases, the lights did not flash when a bike was present. On one of these occasions, two people biking side by side crossed the loops. On another, two cyclists, one riding slightly ahead of the other (not quite side by side), crossed the loops. On one occasion, a recumbent bike with a trailer crossed the loops and was not detected. This suggests detection is sensitive to the type of bicycle and how bikes are positioned on the roadway.

One person on cross country roller skis (short skate like skis with wheels) was detected by the counter. This event was recorded as a correct detection, as this form of non-motorized travel was deemed similar enough to cycling and was detected by the counter, alerting drivers to the presence of a person on the roadway. It is uncommon for people to walk along this rural roadway and no pedestrians were observed by video during the study period.

Oregon upper warning sign near MP 78

From July 22 through August 8, 2019, 227 bikes were observed near MP 78 on the video while the Eco-Counter recorded 238 detections. Of the 238 Eco-Counter detections, review of the video showed 31 of them were motor vehicles (false positives). After subtracting out the false positives, 207 bikes were detected by the Eco-Counter, triggering the flashing lights, when a bike crossed the loops. The formula below was used to calculate the warning system's percent error.

Percent error = (observed value – true value)/ true value X 100

= (207-227)/227 X 100

= - 8.8%

Table 7 shows the parameters used for the MP 84 reliability estimates.

Table 7: Oregon MP 78 Reliability Estimate Parameters and Results

Parameter	Description	Value
Bikes present	Bicycles identified by video review (true value)	227
All Detections	Total Eco-Counter detections (correct and false positives)	238
Correct detections	Bicycles correctly detected by the Eco-Counter (“observed value” for percent error)	207
False positives	The warning sign lights flash when there is no bicycle present.	31 → 13.0% of 238
False negatives	When a bicycle crosses the Eco-Counter loops but is not detected.	21 → 9.3% of 227
Percent Error	Warning system bicycle detection percent error (207 – 227)/227 X 100	– 8.8% undercount

Out of 227 bikes identified by video review, the system correctly detected a bike passing over the Eco-Counter loops 207 times. This approach estimates the system's bicycle detection percent error at -8.8 percent during the study period. In other words, the system undercounted bicycles by 8.8 percent. Therefore, the system correctly detected bicycles 91.2% of the time.

False positives – Among the 238 detections, there were 31 occasions when a motor vehicle was detected by the counter, triggering the lights when no bikes were present. Thus, the system mis-identified a motor-vehicle as a bike on 31 of the 238 counter detections or 13.0 percent of the detections. There did not appear to be a pattern of what type of vehicle triggered the system. Roughly one third (10) of the 31 false positives were vehicles in the opposing (eastbound) lane. Of the 31 false positives, 17 were cars, 12 were larger vehicles (six trucks, two vans, two RVs and two SUVs) and two were motorcycles. Two of the vehicles were pulling trailers. While 13.0 percent of the detections were false positives, over 3,400 motor vehicles crossed the Eco-Counter loops during this time, demonstrating that the system had a relatively low error rate (less than 1%) in terms of distinguishing bicycles from motor vehicles.

False negatives- The system missed detecting 21 of the 227 bicycles observed on video, or 9.3 percent of the time. Of these 21 false negatives, review of the video revealed there were 13 cases when people were riding in groups and the lights were flashing, even though the counter did not detect every bike in the group. In the other eight cases, the lights did not flash when a bike was present. On one occasion, two people biking side by side crossed the loops. On another, two cyclists, one riding slightly ahead of the other (not quite side by side), crossed the loops.

Table 8 summarizes MP 84 and MP 78 reliability parameters and results. The system undercounted bicyclists by 6.3% at MP 84 and by 8.8% at MP 78. Meanwhile, the false positive rate at MP 84 (2.2%) was considerably lower than at MP 78 (13.0%); at the same time, the false negative rate was lower at MP 84 (6.6%) than at MP 78 (9.4%). These differences between the reliability at the two locations may be due to the differences in the internal Eco-Counter settings, vehicle speeds, or road characteristics. For example, mean vehicle speeds near MP 84 ranged from approximately 40-44 mph and the warning sign is located on a relatively straight section of road. In comparison, mean vehicle speeds ranged from approximately 29 mph to 32 mph near MP 78, which is on a curvier section of road where drivers may be more likely to drive on or cross the centerline (possibly producing an electronic signature similar to a bike) and slower moving vehicles are more likely to be detected as false positives.

Table 8: Oregon MP 84 and MP 78 Reliability Summary

	MP 84 Lower	**MP 78 Upper**
Bikes present (Video review)	334	227
All Detections	320	238
Correct bike detections	313	207
False Positives (misidentifications)	7 → 2.2% of 320	31 → 13.0% of 238
False Negatives	21 → 6.3% of 334	21 → 9.3% of 227
Percent Error- bicycle detection	- 6.3% undercount	- 8.8% undercount

2.3.5. Oregon Warning Sign Speed Analysis

This section compares motor vehicle speeds before and after the dynamic warning system installation. Motor vehicle data from the road tubes, including the speed and timestamp for each motor vehicle were delineated into four groups.

5. **Before Sign Bicycles Present group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no

more than 30 seconds before a bicycle passes by the site and up four minutes after a bicycle passes by the site. This timeframe is intended to include drivers whose behavior may be influenced by the presence bicycle on the roadway in the vicinity of the warning sign.

6. **Before Sign Bicycles Absent group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike passed the site. This timeframe is intended to ensure that driver behavior is not influenced by the presence of a person on a bicycle. If a person is cycling at a speed of seven miles per hour, they would be at least a half mile away from a vehicle that arrives at the warning sign five minutes later. On Hwy 242, the lights were set to flash for four minutes, and therefore would be off for a full minute if a motor vehicle arrives five minutes after a bike.

7. **After Sign Bicycles Present group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no more than 30 seconds before a bicycle passes by the site and up four minutes after a bicycle passes by the site.

8. **After Sign Bicycles Absent group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike passed the site.

Motor vehicles that arrived at the warning sign sites within five minutes of a bicycle, but fall outside of the bicycle present groups, were omitted from the analysis. It is not clear if these drivers would be influenced or not by bicyclists, therefore they were omitted to avoid mis-categorizing them.

The discussion starts with the lower warning sign at MP 84, about seven miles west of Sisters, Oregon. This MP 84 sign detects bicycles in the westbound lane, where there is typically a greater speed differential between bikes and motor vehicles due to the uphill topography for westbound travel. The first part provides a visualization and analysis of the raw speed data from the radar. The second part uses a mixed effect model to assess day-to-day speed variation.

Oregon MP 84 Raw Speed Data Visualization and Analysis

Near MP 84, before the warning sign was installed, 103 bicycles were observed in the westbound lane over eight days from June 17-24, 2019. After the sign was installed, 332 westbound bicycles were observed over 14 days between July 23, and August 8, 2019. The road tubes were not installed until July 23rd. As a result, the number of bikes in this speed analysis differs from the number in the reliability assessment, which included data from July 22nd. In addition, portions of the video data were omitted from the analysis due to missing or of insufficient quality to view the flashing lights.

Of the 1831 vehicles in the Before-Sign groups, only one vehicle was omitted because it was within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 1830 vehicles. Of the 4683 vehicles in the After-Sign groups, 413 vehicles were omitted because they were within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 4270 vehicles. Table 9 summarizes the MP 84 data groups.

Table 9: Oregon MP 84 Before and After Bicycles Present/Absent Groups

Group	Motor Vehicles	Total vehicles in Before-Sign and After-Sign Groups
Before Sign Bikes Present	173	1830
Before Sign Bikes Absent	1657	
After Sign Bikes Present	426	4270
After Sign Bikes Absent	3844	

Figure 16 and 17 show road tube speeds near MP 84 in miles per hour (mph). Figure 12 shows speeds for Before-Sign/Bikes Present and Before-Sign/Bikes Absent groups. Figure 13 shows speeds for After-Sign/Bikes Present and After-Sign/Bikes Absent groups. The yellow dots represent vehicle speed for the Bikes-Present groups and the blue dots represent vehicle speed for the Bikes Absent groups.

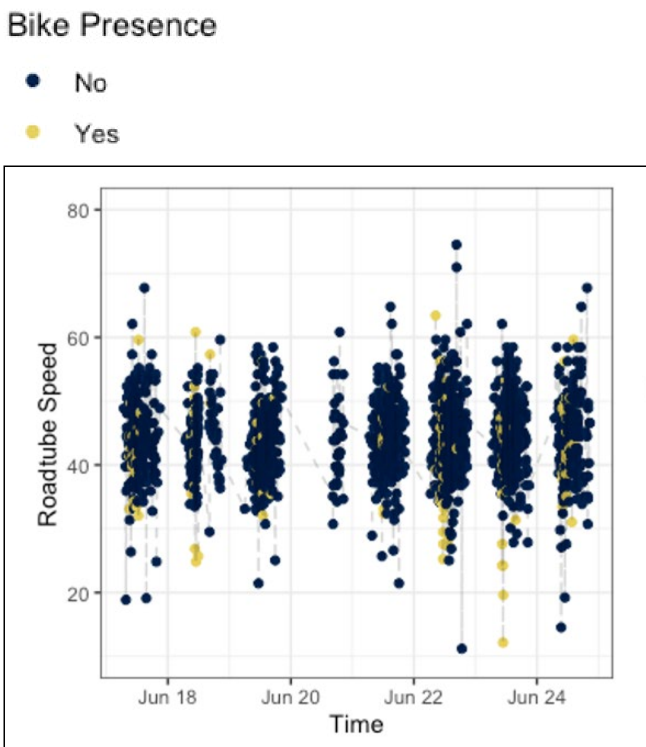

Figure 16: Oregon MP 84 vehicle speeds before warning sign

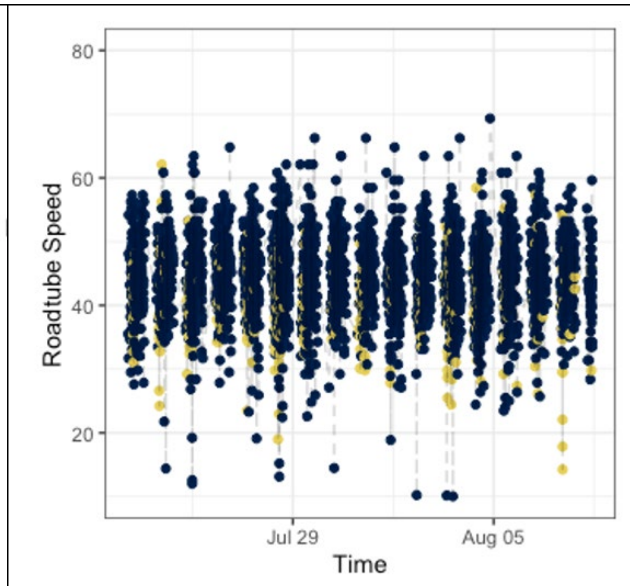

Figure 17: Oregon MP 84 vehicle speeds after warning sign

Table 10 shows vehicle speeds in miles per hour (mph) for the bikes present group. The mean speed, median and 85th percentile speeds decreased after the warning sign was installed by 1.73 mph, 2.37 mph and 2.45 mph respectively.

Table 10: Oregon MP 84 Bicycles Present: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	173	42.12	7.98	12.17	43.2	63.42	49.03
After	426	40.39	6.41	14.26	40.83	62.1	46.58
Difference		**1.73**			**2.37**		**2.45**

Table 11 shows vehicle speeds for the bicycles absent group. Both the mean and median vehicle speeds increased by 0.20 mph and 0.65 mph respectively, while the 85th percentile speed decreased by 0.84 mph.

Table 11: Oregon MP 84 Bicycles Absent: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	1657	44.21	6.16	11.21	43.84	74.52	50.52
After	3844	44.41	5.92	10.04	44.49	69.32	49.68
Difference		**-0.20**			**-0.65**		**0.84**

Figure 18 shows vehicle speed data graphically with the 85th percentile denoted with a red dashed line.

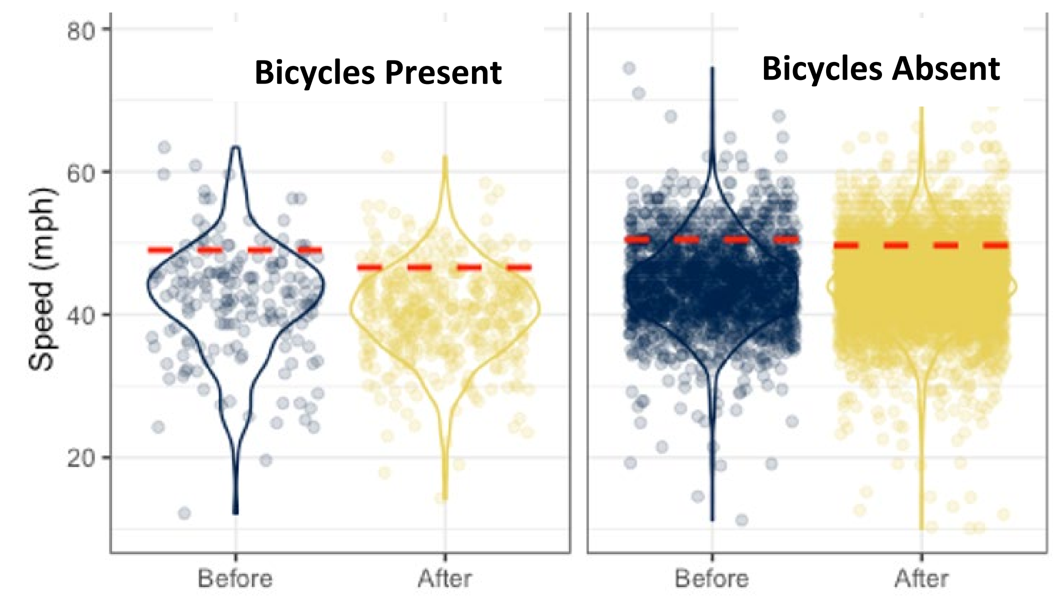

Figure 18: Oregon MP 84 Association between vehicle speed and bicycle presence/absence

Oregon MP 84 Mixed Effect Model Analysis

The previous section provided a visualization and analysis of the raw speed data. There may be variation in vehicle speeds from day to day due to activities such as road maintenance or construction, poor visibility or weather conditions, slow moving vehicles, or other factors. This section analyzes a mixed effect model that was used to assess day-to-day speed variation. Bicycle presence was interacted with before/after sign installation as the fixed effects and date was used as the random intercept.

Adjusted for day-to-day variation, there was very strong evidence that the average speed difference between vehicles before and after the warning sign depends on whether or not a bike was present (t = -3.339, on df = 6027.9864 with p-value = 0.000846). The p-value is a measure of the probability that the observed difference could have occurred by random chance. The lower the p-value, the greater the statistical significance or evidence of the observed difference. This model estimated there was a decrease in mean speed of 1.72 mph when bikes were present and a marginal increase in mean speed of 0.2 mph when bikes were absent after the warning signs were installed versus before. Thus, the difference in mean vehicle speed when bikes were present as compared to when they were absent after the sign was installed was 1.92 mph (1.72mph minus - 0.2 mph). The model shows with 95% confidence that this difference in mean vehicle speed ranged from a decrease of 0.79 mph to 3.05 mph. These results are visualized in the effects plots shown in Figure 19.

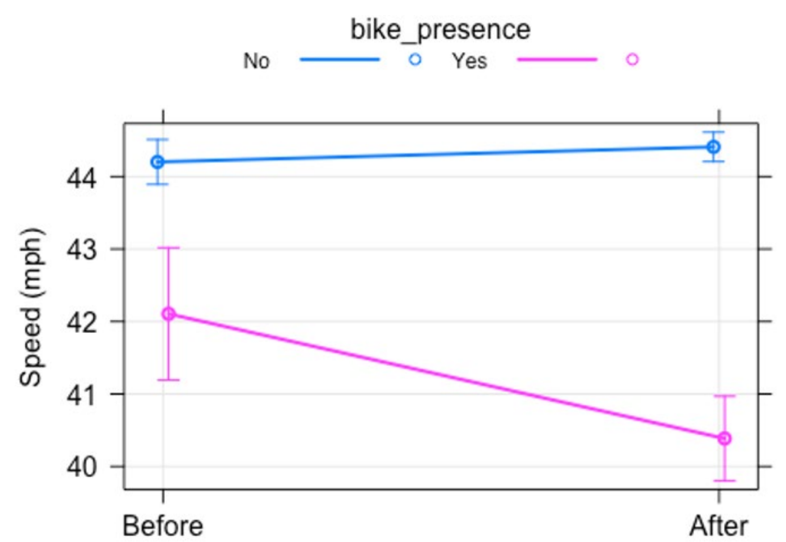

Figure 19: Oregon MP 84 before/after warning sign and presence/absence of bikes effect on vehicle speeds

Notwithstanding the above results, the overall explanatory power of the model is relatively modest, with only 2.97% of the variation in vehicle speed explained by the dynamic warning system, presence/absence of a bike and their interaction in the model (based on the R^2 *marginal* coefficient of determination, which describes the proportion of the variance explained by the fixed factors). Likewise, only 3.01% of the variation in vehicle speed is explained by the interaction between the dynamic warning system and presence/absence of bikes, their marginal effects and day-to-day variability in the model (based upon the R^2 *conditional* coefficient of determination, which describes the proportion of variance explained by both the fixed and random factors).

Next, four inquiries were tested as described below, controlling for day-to-day variation, with results shown in Table 4, where H_0 is the null hypothesis and μ is the mean vehicle speed.

Inquiry 1) *H_0: μ Before Sign Bikes Present – μ After Sign Bikes Present = 0*

When bicycles are present, the difference in mean vehicle speeds before minus after the warning sign was introduced equals zero.

Inquiry 2) *H_0: μ Before Sign Bikes Absent – μ After Sign Bikes Absent = 0*

When bicycles are absent, the difference in mean vehicle speed before minus after the warning sign was introduced equals zero.

Inquiry 3) *H_0: μ Before Sign Bikes Present – μ Before Sign Bikes Absent = 0*

Before the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when bikes were absent equals zero.

Inquiry 4) *H_0: μ After Sign/Bikes Present – μ After Sign/Bikes Absent = 0*

After the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when absent equals zero.

Table 12 summarizes the evidence with regard to the four inquiries described above.

Table 12: Oregon MP 84 Inquiry Summary for Changes in Mean Vehicle Speeds

Inquiry/ Null Hypothesis H_0	Change in mean vehicle speed (mph) μ	95% confidence interval (mph)	Two-sided p-value
1) When bikes present, mean vehicle speed before minus after = zero	1.72 mph (slower after)	0.638 to 2.8 mph	0.0018 (strong evidence to reject H_0)
2) When bikes absent, mean vehicle speed before minus after = zero	-0.2 mph (faster after)	-0.57 to 0.169 mph	0.169 (insufficient evidence to reject H_0)
3) Before warning sign installed, mean vehicle speed when bikes present minus absent = zero	-2.1 mph (faster when bikes absent)	-3.06 to -1.15 mph	<0.0001 (strong evidence to reject H_0)
4) After warning sign installed, mean vehicle speed when bikes present minus absent = zero	-4.02 mph (faster when bikes absent)	-4.63 to -3.41 mph	<0.0001 (strong evidence to reject H_0)

In terms of Inquiry 1, mean vehicle speeds were estimated to be 1.72 mph slower after the warning sign was introduced. As a result, there is sufficient evidence to reject the null hypothesis that the mean vehicle speeds do not differ. The estimated mean vehicle speeds decreased in the presence of bikes.

In terms of Inquiry 2, mean vehicle speeds were estimated to be 0.2 mph faster after the warning sign was introduced. However, there is insufficient evidence to reject the null hypothesis that the mean vehicle speeds do not differ from zero. We therefore cannot conclude that the mean vehicle speed in the absence of bikes differs before versus after the warning signs were introduced.

In terms of Inquiry 3, mean vehicle speeds were estimated to be 2.1 mph faster when bikes were absent. There is sufficient evidence to reject the null hypothesis that the mean vehicle speeds do not differ. In other words, before the warning signs were introduced, it is likely the mean vehicle speed differed based on the presence of a bicyclist.

In terms of Inquiry 4, mean vehicle speeds were estimated to be 4.02 mph faster when bikes were absent, and there is sufficient evidence to reject the null hypothesis that the mean vehicle speeds do not differ.

In conclusion, the model suggests there is sufficient evidence to conclude that there was likely a decrease in vehicle speeds after the MP 84 warning sign was introduced, and the magnitude of change was associated with the presence or absence of a bicycle. When bicycles were present, mean vehicle speed decreased after warning sign installation by an estimated 1.72 mph. However, this model suggests that only a small proportion of total variability in vehicle speed (about 3%) may be explained by the MP 84 warning sign. Results from this analysis can only be generalized to the population of vehicles observed over the days from 6/17/19 to 6/24/19 and 7/23/19 to 8/8/19, or vehicles similar to those that were observed. Since this is an observational study, our conclusions are based on an association between the installation of the dynamic warning sign and vehicle speed in the presence or absence of bicycles. In other words, no causal inferences can be made.

A summary of MP 84 and MP 78 results follow the MP 78 section below.

Oregon MP 78 Raw Speed Data Visualization and Analysis

Near MP 78, before the warning sign was installed, 109 bicycles were observed in the westbound lane over eight days from June 17-24, 2019. After the sign was installed, 222 westbound bicycles were observed over 14 days between July 23, and August 8, 2019. The road tubes were not installed until July 23rd. As a result, the number of bikes in this speed analysis differs from the number in the reliability assessment, which included data from July 22nd. In addition, portions of the video data were omitted from the analysis due to missing or of insufficient quality to view the flashing lights.

Of the 1666 vehicles in the Before Sign groups, only one vehicle was omitted because it was within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 1665 vehicles. Of the 3421 vehicles in the After-Sign groups, 299 vehicles were omitted because they were within ± five minutes from a bike but not in the Bicycle Present group as previously defined, resulting in 3122 vehicles. Table 13 summarizes the MP 78 data groups.

Table 13: Oregon MP 78 Before and After Bicycles Present/Absent Groups

Group	Motor Vehicles	Total vehicles in Before-Sign and After-Sign Groups
Before Sign Bikes Present	146	1665
Before Sign Bikes Absent	1519	
After Sign Bikes Present	360	3122
After Sign Bikes Absent	2762	

Figure 20 and 21 show road tube speeds near MP 78 in mph. Figure 16 shows speeds for Before-Sign/Bikes Present and Before-Sign/Bikes Absent groups. Figure 17 shows speeds for After-Sign/Bikes Present and After-Sign/Bikes Absent groups. The yellow dots represent vehicle speed for the bicycle present group and the blue dots represent vehicle speed for the bicycles absent group.

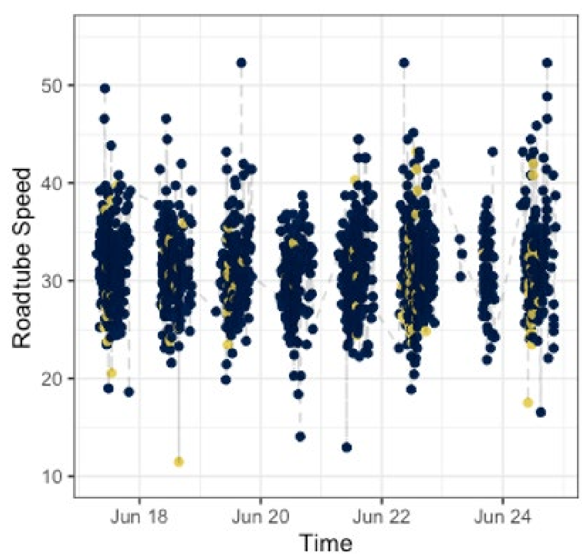

Figure 20: Oregon MP 78 vehicle speeds before warning sign

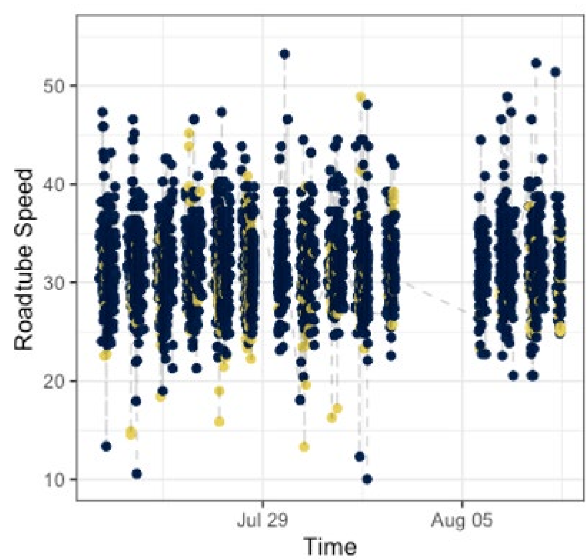

Figure 21: Oregon MP 78 vehicle speeds after warning sign

Table 14 shows vehicle speeds in miles per hour (mph) for the bicycles present group. The mean speed, median and 85th percentile speeds increased slightly after the warning sign was installed by 0.12 mph, 0.45 mph and 0.28 mph respectively.

Table 14: Oregon MP 78 Bicycles Present: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	146	29.88	4.37	11.46	29.66	43.20	33.21
After	360	30.00	4.35	13.31	30.11	48.87	33.49
Difference		**-0.12**			**-0.45**		**-0.28**

Table 15 shows vehicle speeds for the bicycles absent group. Both the mean and median vehicle speeds increased by 0.46 mph and 0.33 mph respectively, while the 85th percentile speed remained the same.

Table 15: Oregon MP 78 Bicycles Absent: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	1519	31.19	4.29	12.96	31.05	52.30	35.07
After	2762	31.65	4.00	10.04	31.38	53.23	35.07
Difference		**-0.46**			**-0.33**		**0**

Figure 22 shows vehicle speed data graphically with the 85th percentile denoted with a red dashed line, demonstrating that the 85th percentile speed is higher when bicycles are absent both before and after the warning signs were installed. This suggests people tend to drive somewhat slower when they are near a bicycle.

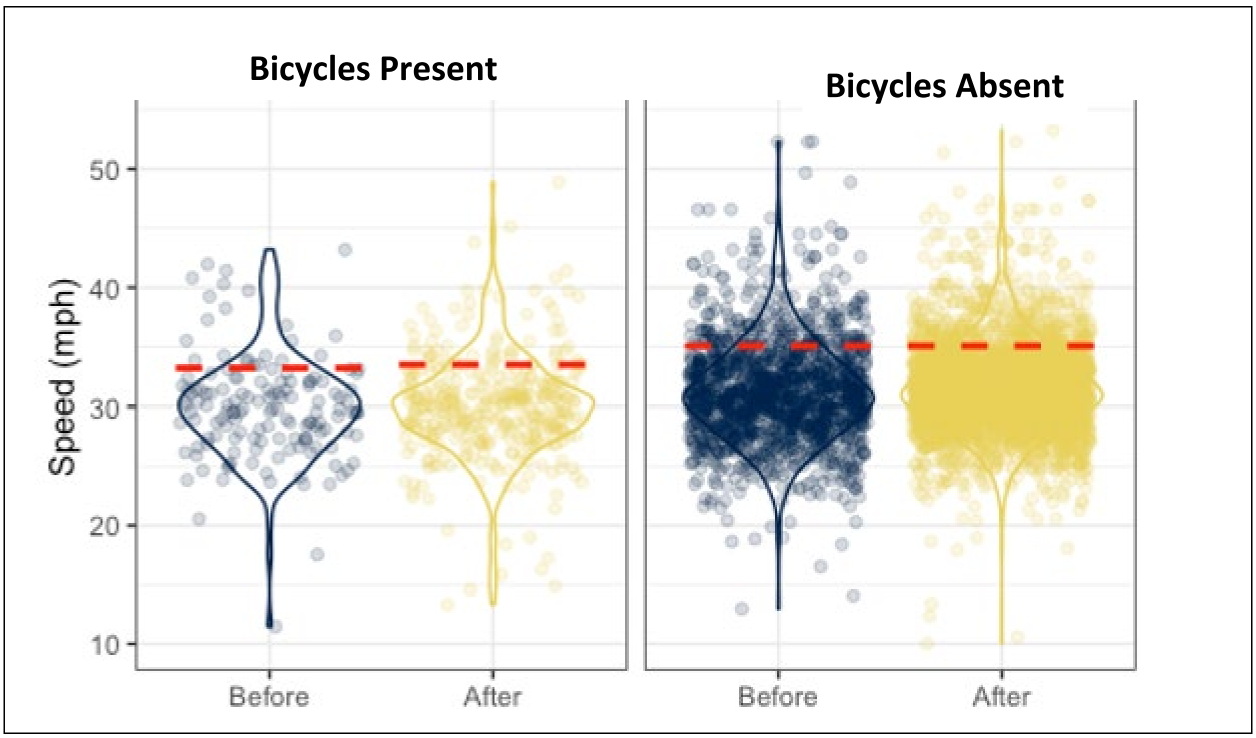

Figure 22: Oregon MP 78 association between vehicle speed and bicycle presence/absence

Oregon MP 78 Mixed Effect Model Analysis

A mixed effect model was used to assess day-to-day speed variation. Bicycle presence was interacted with before/after as the fixed effects and date as the random intercept.

Adjusted for day-to-day variation, there is weak evidence that the average speed difference between vehicles before and after the warning sign depends on whether or not a bike was present (t = -0.777, on df = 4289.82 with p-value = 0.437379). The p-value is a measure of the probability that the observed difference could have occurred by random chance. The lower the p-value, the greater the statistical significance or evidence of the observed difference. This model estimates an increase in mean speed of 0.127 mph when bikes were present and an increase of 0.459 mph when bikes were absent after the warning signs were installed versus before. Thus, there is a slightly smaller increase in mean speed when bikes were present as compared to when they were absent after the sign was installed (0.127 minus .0459 mph= .332). The model shows with 95% confidence that this difference in mean vehicle speed when bikes were present versus absent ranges between a 1.17 mph decrease to an increase of 0.50 mph.

The overall explanatory power of the model is relatively modest, with only 1.5% of the variation in vehicle speed explained by the dynamic warning system, presence/absence of a bike and their interaction in the model (based on the R^2 *marginal* coefficient of determination, which describes the proportion of the variance explained by the fixed factors). Likewise, only 1.6% of the variation in vehicle speed is explained by the interaction between the dynamic warning system and presence/absence of bikes, their marginal effects and day-to-day variability in the model (based upon the R^2 *conditional* coefficient of determination, which describes the proportion of variance explained by both the fixed and random factors). These results are visualized in the effects plots shown in Figure 23.

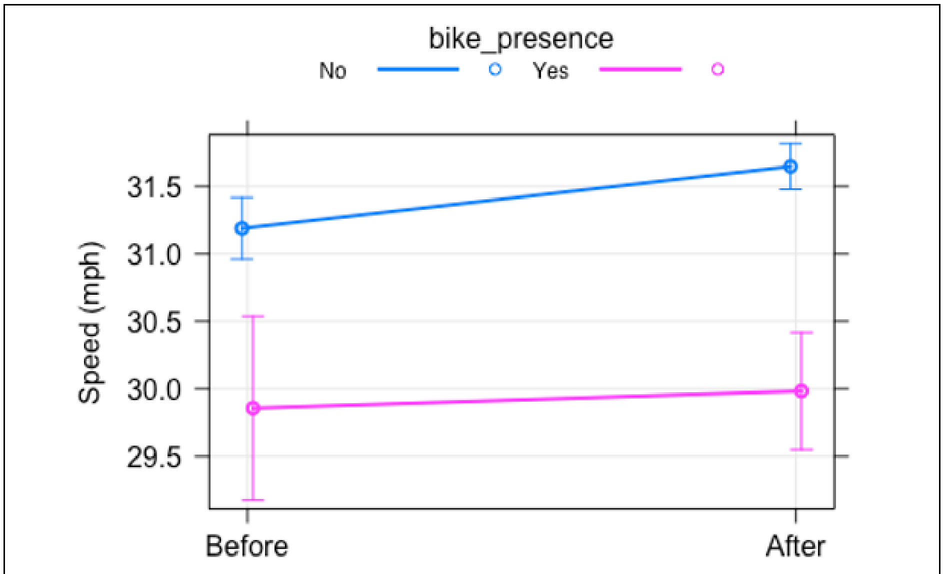

Figure 23: Oregon MP 78 before/after warning sign and bike presence/absence effect on vehicle speeds

As expected, the average speed is lower when a bike is present compared to when there is no bike present. However, surprisingly, average motor vehicle speed increased slightly after the warning sign was introduced compared to before regardless of whether a bike was present or not.

Next, four inquiries were tested as described below, controlling for day-to-day variation, with results shown in Table 12, where H_0 is the null hypothesis and μ is the mean vehicle speed.

Inquiry 1) *H_0: μ Before Sign Bikes Present – μ After Sign Bikes Present = 0*

When bicycles are present, the difference in mean vehicle speeds before minus after the warning sign was introduced equals zero.

Inquiry 2) *H_0: μ Before Sign Bikes Absent – μ After Sign Bikes Absent = 0*

When bicycles are absent, the difference in mean vehicle speed before minus after the warning sign was introduced equals zero.

Inquiry 3) *H_0: μ Before Sign Bikes Present – μ Before Sign Bikes Absent = 0*

Before the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when bikes were absent equals zero.

Inquiry 4) *H_0: μ After Sign/Bikes Present – μ After Sign/Bikes Absent = 0*

After the warning sign was introduced, the difference in mean vehicle speeds when bikes were present minus when absent equals zero.

Table 16 summarizes the evidence with regard to the four inquiries described above.

Table 16: Oregon MP 78 Inquiry Summary for Changes in Mean Vehicle Speeds

Inquiry/ Null Hypothesis H_0	**Change in mean vehicle speed (mph) μ**	**95% confidence interval (mph)**	**Two-sided p-value**
1) When bikes present, mean vehicle speed before minus after = zero	-0.127 mph (faster after)	-0.933 to 0.679 mph	0.7571 (insufficient evidence to reject H_0)
2) When bikes absent, mean vehicle speed before minus after = zero	-0.459 mph (faster after)	-0.744 to -0.174 mph	0.0016 (strong evidence to reject H_0)
3) Before warning sign installed, mean vehicle speed when bikes present minus absent = zero	-1.33 mph (faster when bikes absent)	-2.03 to -0.629 mph	0.0002 (strong evidence to reject H_0)
4) After warning sign installed, mean vehicle speed when bikes present minus absent = zero	-1.66 mph (faster when bikes absent)	-2.12 to -1.21 mph	<0.0001 (strong evidence to reject H_0)

In terms of inquiry 1, mean vehicle speeds were estimated to be 0.127 mph faster after the warning sign was introduced when bikes are present. However, there is insufficient evidence that this change differs from zero. We would conclude that vehicle speeds did not change in the presence of bikes, after the warning signs were introduced.

In terms of inquiry 2, mean vehicle speeds were estimated to be 0.459 mph faster after the warning sign was introduced when bikes are absent. There is strong evidence that this differs from 0 mph. We would conclude that when bikes were absent, the estimated mean vehicle speed after the warning sign was introduced is slightly higher than the vehicle speed before the warning sign was introduced.

In terms of inquiry 3, mean vehicle speeds were estimated to be 1.33 mph faster when bikes were absent. There is very strong evidence that this difference differs from 0 mph. We would conclude that vehicle speeds before the warning sign was introduced were higher in the absence of bikes that when bikes were present.

In terms of inquiry 4, mean vehicle speeds were estimated to be 1.66 mph faster when bikes were absent. There is very strong evidence that this difference differs from 0 mph. We would conclude that vehicle speeds after the warning sign was introduced were higher in the absence of bikes, than when bikes were present.

In conclusion, near MP 78 the model suggests that there was a slight increase in mean vehicle speeds after the dynamic warning systems were introduced, and this association is similar whether a bike is present or not. When bicycles were present, there was insufficient evidence that the small increase in mean speeds is different than it would be by random chance. This model suggests that only a small proportion of total variability in vehicle speed (about 1.5%) may be explained by the MP 78 warning sign. Results from this analysis can only be generalized to the population of vehicles observed over the days from 6/17/19 to 6/24/19 and 7/23/19 to 8/8/19, or vehicles similar to those that were observed. Since this is an observational study, our conclusions are based on an association between the installation of the dynamic warning sign and vehicle speed in the presence or absence of bicycles. In other words, no causal inferences can be made.

Oregon MP 84 and MP78 Speed Analysis Summary

Vehicle speed is relatively simple to measure, and the intent of this project was to use speed as a proxy for safety, with the understanding that slower motor vehicle speeds generally result in a safer environment for people riding bikes. However, it is not clear that lowering mean motor vehicle speeds at MP 84 from approximately 42 mph to 40 mph will have a significant impact on bicycle safety. Results from a study on vehicle/pedestrian impacts shows that “the average risk of severe injury for a pedestrian struck by a vehicle reaches 10% at an impact speed of 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph. The average risk of death for a pedestrian reaches 10% at an impact speed of 23 mph, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph.” (Tefft, B.C. 2011)

For MP 78, the speed analysis results suggested a slight increase in mean vehicle speeds when bikes were present after the warning sign was installed, though there was insufficient evidence that the change is different than it would be by random chance.

Given that motor vehicle speeds were lower when bicycles were present may indicate that drivers are aware of their presence. However, this data analysis suggests that there are many factors that affect motor vehicle speeds and that the warning system and presence of bicycles have some influence, but do not appear to have a major influence on vehicle speeds.

2.3.6. Oregon Warning Sign Facility Owner Perceptions

On July 20, 2021, WTI conducted an online focus group with seven ODOT Region 4 personnel including the Active Transportation Liaison, District Manager, Electrical Supervisor, two electricians, a Traffic Manager and Statewide Traffic Engineer. A list of 19 questions was sent in advance to contacts that have worked on this project. These individuals were involved in different parts of the project including helping plan the system, conducting oversight, system design and purchasing equipment, installation, and gaining necessary ODOT approvals. The discussion is summarized in the five categories below.

1) Observations of bicycle/vehicle interactions

The dynamic warning systems are on rural Hwy 242, over 30 miles from ODOT's Bend offices. Thus, most staff rarely travel by the systems. This site is unique as the road is only open six months a year (closed during snowy months). The active transportation liaison downloaded counter data about once a month in 2019 (pre-Covid) and observed that motor vehicles at the lower site near MP 84 tended to swing wide and pass bikes. The electricians spent a significant amount of time on site troubleshooting while installing the systems. During that time, they reported that people were curious about how the system worked, though they did not report observations of bike/vehicle interactions. While onsite, the electricians heard feedback from cyclists that they appreciate the systems.

2) Installation process

There were a few glitches in how the Eco-Counter system interfaced with the flashers that required troubleshooting. Other than that, the installation went well. If this is viewed as off the shelf system, then no, the installation did not go smoothly. If this is viewed as a research prototype, then yes, the installation went smoothly.

3) Maintenance and Eco-Counter function

No maintenance has been performed on the systems since they were installed two years ago. An ODOT electrician visited site on July 19, 2021, and reported the equipment looked good. ODOT electricians had a good understanding of how to maintain the solar panels and batteries. They reported that it is easy to reach Eco-Counter for information.

4) Bicycle count data retrieval and online analysis/viewing

ODOT's Region 4 Active Transportation Liaison reported it is simple to download data from the counters. They have a good understanding of how the Eco-Visio online program works, though noted there is a learning curve.

5) Thoughts on system and advice for others

When asked "To what level do you agree with the following statement. I would recommend dynamic warning sign systems as a tool for other road managers/operators to help raise awareness for people driving about the presence of people riding bicycles on rural roads." Most of this group "neither agree nor disagree".

Some comments made were that these systems are probably helpful if there is a specific constraint, like a tunnel or narrow bridge that would push bikes into the motor vehicle lane. For Hwy 242, a 15-mile-long curvy road, with only two warning signs, at what point do you lose driver attentiveness? Alternatively, you don't want to litter the corridor with signs.

Another comment was that this warning system looks like school or warning flashers that are always on or on at a set time. The public sees the sign and they don't realize it is triggered by bikes. The system must work 100% of the time and may lose drivers attention if flashing appears random and they don't see bikes.

While this group would not necessarily strongly recommend this system to others, there is hesitancy to remove this tool from the toolbox. It could be a good tool under the right conditions considering sight distance in limited locations. There was interest in seeing how these systems work in other contexts as well as having strong criteria around where these signs are appropriate. From design, installation, and maintenance, it is important to have consistency and ensure that the different parts of system (like counter and flashing lights/timer) work together before installing in the field. The installers had some specific advice regarding installation which have been incorporated into section 2.2.2.

ODOT has a statewide dashboard of Eco-Counter data. However, there is no cellular service at sites and no regular funding mechanisms for bike counts as there is for motor vehicle counts.

2.3.7. Idaho Warning Sign Reliability

Idaho site monitoring consisted of video and radar data collected before the warning sign installation between September 26 and October 6, 2019, and after the sign was installed between June 19 and July 6, 2020. More data was collected, but these are the dates when video and radar data overlap. Video is missing for part of this time, primarily due to batteries running low.

WTI staff reviewed video footage, recording the number of eastbound and westbound bicycles and pedestrians with their video timestamp in an Excel spreadsheet. Riverside Road is close to Bonners Ferry and it is commonly used by people walking and biking, which is different from the Oregon and Colorado sites. For the June and July 2020 video, after the warning signs were in place, staff recorded when the lights were flashing. Radar data timestamps were adjusted to match the associated motor vehicle timestamps observed in the video. Data collection in the fall, before the signs were installed was limited to daylight hours between 6:30 am and 7:00 pm. Data collection in the spring, after the signs were installed was limited to daylight hours between 5:00 am and 9:00 pm.

Data collection went relatively smoothly for the Idaho East sign. However, due to schedule changes and miscommunication, the video data was not collected for the West sign before the system was installed. In addition, video collected after the West sign was installed was of insufficient quality to perform a meaningful analysis. Therefore, the analysis that follows is for the East sign only. The two signs are identical in design, thus results from the East sign may inform decisions for both systems. The following sections describe analysis of the warning system reliability and the before and after vehicle speed.

Riverside Road Idaho East warning sign

Video footage was reviewed and compared to the Eco-Counter data to determine the warning system reliability and the following items were assessed:

- Correct detections – the system activates when a bicycle passes over the Eco-Counter inductive loops.
- False positives (misidentifications) – the system activates when there is no bicycle present.
- False negatives – the system does not activate when a bicycle passes over the Eco-Counter inductive loops.

From June 19 and July 6, 2020 (after the sign was installed), 34 bikes were observed near the East warning sign on the video (the “true value”) while the Eco-Counter recorded 56 detections. Of the 56 Eco-Counter detections, review of the video showed 24 of them were motor vehicles (false positives). After subtracting out the false positives, 32 bikes (the “observed value”) were detected by the Eco-Counter. The bicycle detection error rate of the Eco-Counter can be estimated by taking the difference between the “observed value” and the “true value” in comparison to the “true value” and multiplying by 100 to express as a percentage, as summarized in the following formula.

Percent error = (observed value – true value)/ true value X 100

= (32-34)/34 X 100

= - 5.9%

Table 17 shows the parameters used for the Idaho East warning sign reliability estimates. Out of 34 bikes identified by video review, the system correctly detected a bike passing over the Eco-Counter loops 32 times. This approach estimates the system’s bicycle detection percent error at -5.9 percent during the study period. In other words, the system undercounted bicycles by 5.9 percent. Therefore, the system correctly detected bicycles 94.1 percent of the time.

Table 17: Idaho East Reliability Estimate Parameters and Results

Parameter	Description	Value
Bikes present	Bicycles identified by video review (true value)	34
All Detections	Total Eco-Counter detections (correct and false positives)	56
Correct detections	Bicycles correctly detected by the Eco-Counter ("observed value" for percent error)	32
False positives	The warning sign lights flash when there is no bicycle present.	24 → 42.9 % of 56
False negatives	When a bicycle crosses the Eco-Counter loops but is not detected.	2 → 3.6% of 34
Percent Error	Warning system bicycle detection percent error (32-34)/34 X 100	-5.9 % undercount

False positives- Among the 56 total detections, there were 24 occasions when a motor vehicle was detected by the counter, triggering the lights when there were no bikes present. Thus, the system mis-identified a motor vehicle as a bike on 24 of the 56 counter detections or 42.9% of the detections. Of these 24 false positives, nine were vehicles that passed westbound over the Eco-Counter loops and 12 were vehicles in the eastbound lane. All 12 of the eastbound vehicles appeared to be driving on the centerline and included four pickup trucks, three trucks pulling a camper or boat, two SUVS, one logging truck, one combine and one tractor. The nine westbound vehicles included three pickup trucks, one tractor, one combine, one truck pulling a boat and three smaller vehicles (a utility task vehicle or side by side, a four-wheeler and a motorcycle). This high rate of false positives is in part due to the low number of bikes present during the study period. While the false positives are a high percentage of the Eco-Counter detections, almost 2400 motor vehicles crossed the loops westbound during this time, demonstrating the system had a relatively low error rate (56/2400= 2.3%) in terms of distinguishing bicycles from motor vehicles. Many of these false positives were large slow-moving vehicles that triggered the lights, which may not necessarily be viewed as a bad thing on this rural road with mixed traffic.

False negatives- The system missed two of the 34 bicycles observed on video, or 3.6% percent of the bikes. In both cases, two people were riding together, and the lights were flashing, even though the counter only detected one rider in each pair.

2.3.8. Idaho Warning Sign Speed Analysis

This section compares motor vehicle speeds before and after the dynamic warning system installation. The speed limit is 25 miles per hour on this section of Riverside Road. Motor vehicle data from the radar, including the speed and timestamp for each motor vehicle were delineated into four groups.

1. **Before Sign Bicycles/Pedestrians Present group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no more than 30 seconds before a bicycle or pedestrian passes by the site and up to four minutes after a bicycle or pedestrian passes by the site. This timeframe is intended to include drivers whose behavior may be influenced by the presence of a person walking or biking in the westbound lane in the vicinity of the warning sign.

2. **Before Sign Bicycles/Pedestrians Absent group:** Refers to the study period before the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike/pedestrian passed the site. This timeframe is intended to ensure that driver behavior is not influenced by the presence of a person biking or walking. If a person is cycling at a speed of seven miles per hour, they would be at least a half mile away from a vehicle that arrives at the warning sign five minutes later. On Riverside Road, the lights flash for three minutes, and therefore would be off for two minutes if a motor vehicle arrives five minutes after a bike.

3. **After Sign Bicycles/Pedestrians Present group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site no more than 30 seconds before a bicycle or pedestrian passes by the site and up four minutes after a bicycle/pedestrian passes by the site.

4. **After Sign Bicycles/Pedestrians Absent group:** Refers to the study period after the warning signs were installed. Includes westbound motor vehicles that pass by the warning sign site at least five minutes before or after a bike or pedestrian passed the site.

Motor vehicles that arrived at the warning sign sites within five minutes of a bicycle/pedestrian, but that fall outside of the bicycle/pedestrian present groups, were omitted from the analysis. It is not clear if these drivers would be influenced or not by bicyclists/pedestrians, therefore they were omitted to avoid mis-categorizing them.

The following section discusses the warning sign located on Riverside Road on the east side of Ambush Rock, near Bonners Ferry. This sign detects bicycles in the westbound lane, where there is typically a greater speed differential between bikes and motor vehicles due to the uphill topography for westbound travel. The first part provides a visualization and analysis of the raw speed data from the radar. The second part uses a mixed effect model to assess day-to-day speed variation.

Riverside Road Idaho East Warning Sign Raw Speed Data Visualization and Analysis

Riverside Road is unique from the other sites in that it is used by pedestrians as well as people biking. There was construction at the Kootenai Wildlife Refuge during this project and the refuge road, which is a destination for people biking was closed. This construction combined with cool, wet weather in the fall likely led to fewer bikes than is typical riding on Riverside Road in the vicinity of the warning signs.

Near the Idaho East sign, before the warning sign was installed, 31 bicycles and pedestrians (27 pedestrians and 4 bikes) were observed in the westbound lane between September 26 and October 6, 2019. After the sign was installed, 46 bicycles and pedestrians (19 pedestrians and 27 bikes) were observed in the westbound lane between June 19 and July 6, 2020. The number of bikes in this speed analysis differs from the number in the reliability assessment by seven. There were no motor vehicles within five minutes of these bikes, so their presence does not impact the speed analysis. This analysis includes westbound bike and pedestrian data, as it is anticipated that both pedestrians and bikes on the roadway may influence vehicle speeds.

Of the 1661 vehicles in the Before Sign groups, 53 vehicles were omitted because they were within ± five minutes from a bike/pedestrian but not in the Bike/Pedestrian Present group as previously defined, resulting in 1608 vehicles (33 when bikes/peds present and 1575 when bikes/peds absent). Of the 2380 vehicles in the After Sign groups, 54 vehicles were omitted because they were within ± five minutes from a bike/pedestrian but not in the Bike/Pedestrian Present group as previously defined. Three vehicles were omitted since their speeds were not recorded by the radar, resulting in 2323 vehicles in the After Sign group (54 when bikes/peds present and 2269 when bikes/peds absent). Table 18 summarizes the Idaho East sign data groups.

Table 18: Idaho East Before and After Bicycles/Pedestrians Present/Absent Groups

Group	Motor Vehicles	Total vehicles in Before-Sign and After-Sign Groups
Before Sign Bike/Ped Present	33	1608
Before Sign Bike/Ped Absent	1575	
After Sign Bike/Ped Present	54	2323
After Sign Bike/Ped Absent	2269	

Figure 24 and Figure 25 show radar speeds near the Idaho East sign in mph. Figure 20 shows vehicle speeds for Before Sign Bikes Present and Absent groups. Figure 21 shows speeds for the After Sign Bikes Present and Absent groups. The yellow dots represent vehicle speeds when bikes are present, and the blue dots represent vehicle speeds when bikes are absent.

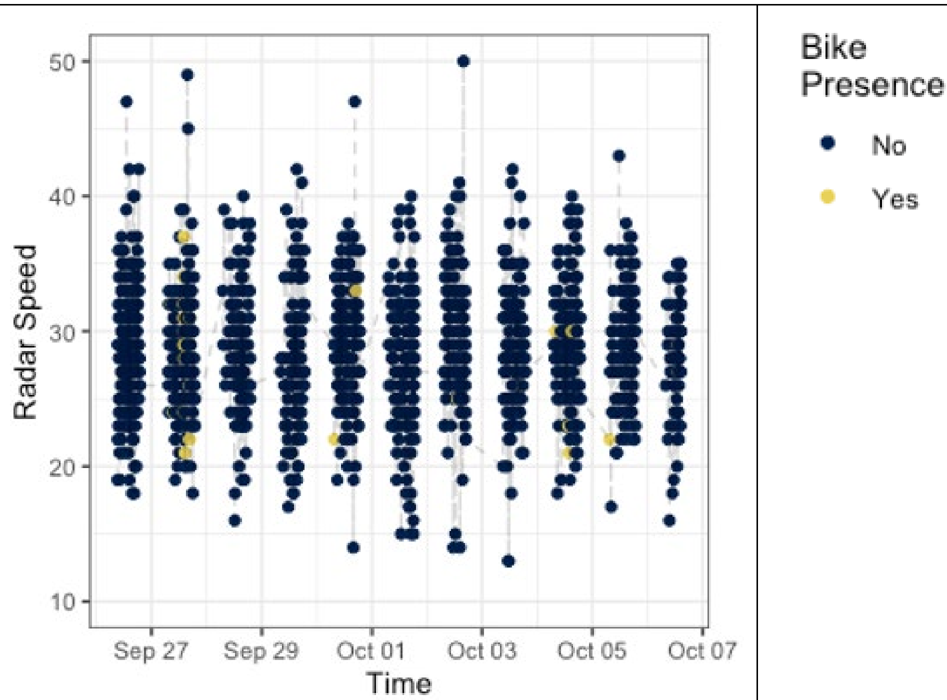

Figure 24: Idaho East vehicle speeds before warning sign

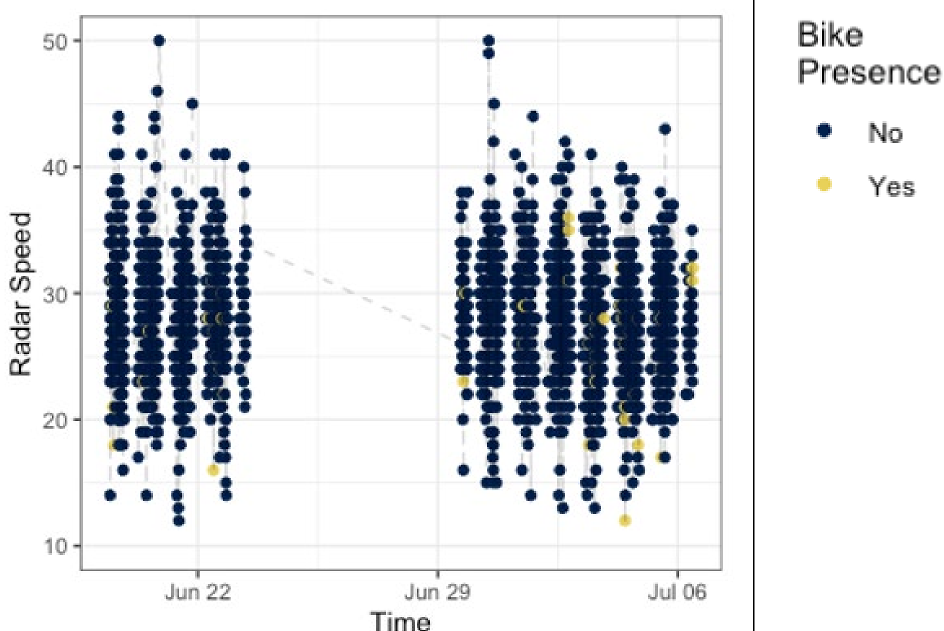

Figure 25: Idaho East vehicle speeds after warning sign

Table 19 shows vehicle speeds in miles per hour (mph) for the bikes and pedestrians present group. The mean speed, median and 85th percentile speeds decreased after the warning sign was installed by 1.98 mph, 2 mph and 1 mph respectively.

Table 19: Idaho East Bicycles/Pedestrians Present: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	33	27.85	4.31	21	29	37	32
After	54	25.87	4.84	12	27	36	31
Difference		**1.98**			**2**		**1**

Table 20 shows vehicle speeds for the bicycles/pedestrian absent group. After the warning sign was installed, both the mean and median vehicle speeds decrease by 0.63 mph and 1 mph respectively, while the 85th percentile speed did not change.

Table 20: Idaho East Bicycles/Pedestrians Absent: Before and After Vehicle Speeds (mph)

Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Before	1575	28.66	4.7	13	29	50	33
After	2269	28.03	4.82	12	28	53	33
Difference		**0.63**			**1**		**0**

Figure 26 shows vehicle speed data graphically with the 85th percentile denoted with a red dashed line. The image on the left shows there are relatively few vehicles present when bikes/pedestrians are on the roadway and vehicle speeds tend to be lower after the warning sign was installed. The figure on the right shows there are many more vehicles when there are no bikes on the road and their speeds appear relatively consistent before and after the warning sign was installed. It also shows the 85th percentile speeds (red dashed line) tend to be higher when there are no bikes/pedestrians present in the westbound lane.

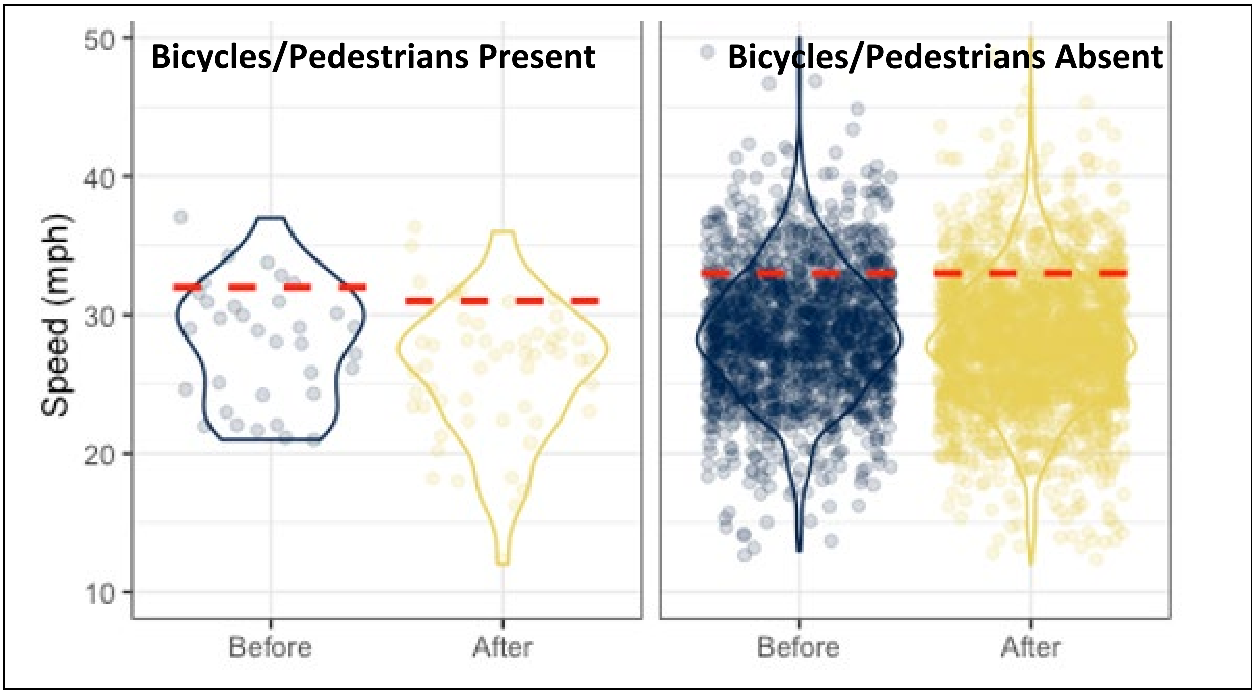

Figure 26: Idaho East association between vehicle speed and bicycle/pedestrian presence and absence

Idaho East Warning Sign Mixed Effect Model Analysis

A mixed effect model was used to assess day-to-day speed variation. Bicycle/pedestrian presence was interacted with before/after the warning system was installed as the fixed effects and date as the random intercept. Adjusted for day-to-day variation, there is weak evidence that the average speed difference between vehicles before and after the warning sign depends on whether or not a bike or pedestrian was present (t = -1.045, on df = 3853.6324 with p-value = 0.2960). The p-value is a measure of the probability that the observed difference could have occurred by random chance. The lower the p-value, the greater the statistical significance or evidence of the observed difference. This model estimates a decrease in mean speed of 1.69 mph when bikes/peds were present and a decrease of 0.57 mph when bikes/peds were absent after the warning signs were installed versus before. Thus, mean speed decreases more when bikes/peds were present as compared to when they were absent after the sign was installed (1.69-.057 = 1.21). mph). The model shows with 95% confidence that this difference in mean vehicle speed when bikes were present versus absent ranges between a 3.24 mph decrease to an increase of 0.97 mph. These results are visualized in the effects plots shown in Figure 27.

The overall explanatory power of the model is relatively modest, with only 0.632% of the variation in vehicle speed explained by the dynamic warning system, presence/absence of bike/pedestrian and their interaction in the model (based on the R^2 *marginal* coefficient of determination, which describes the proportion of the variance explained by the fixed factors). Likewise, only 1.39% of the variation in vehicle speed is explained by the interaction between the dynamic warning system and presence/absence of bikes, their marginal effects and day-to-day variability in the model (based upon the R^2 *conditional* coefficient of determination, which describes the proportion of variance explained by both the fixed and random factors). As expected, we see that the average speed is lower after the warning sign compared to before its installment. However, the lines are relatively parallel suggesting that this relationship is similar with or without the presence of bicycles/pedestrians, hence there is limited interaction between the warning sign and bike/pedestrian presence.

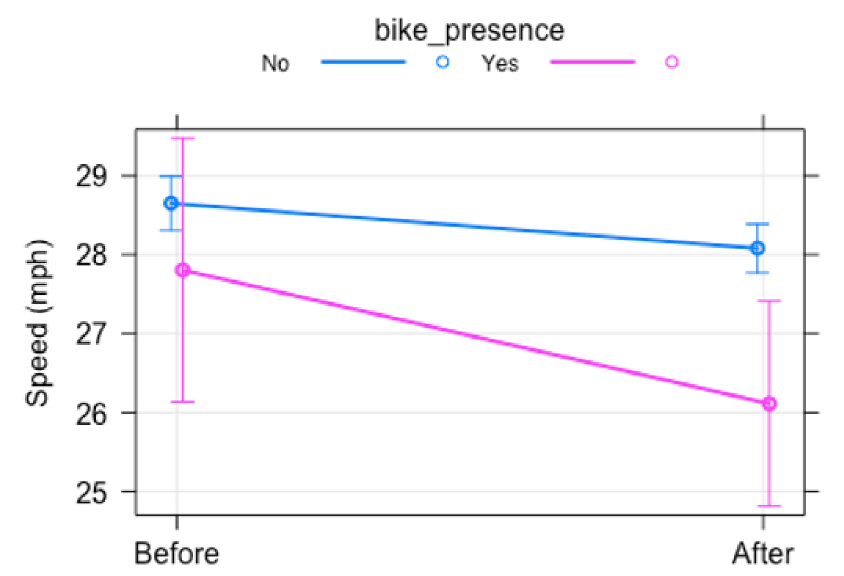

Figure 27: Idaho East before/after warning sign and presence/absence of bikes/peds effect on vehicle speed

Next, four inquiries were tested as described below, controlling for day-to-day variation, with results shown in Table 21, where H_0 is the null hypothesis and μ is the mean vehicle speed.

Inquiry 1) *H_0: μ Before Sign Bikes Present – μ After Sign Bikes Present = 0*

When bicycles/pedestrians are present, the difference in mean vehicle speeds before minus after the warning sign was introduced equals zero.

Inquiry 2) *H_0: μ Before Sign Bikes Absent – μ After Sign Bikes Absent = 0*

When bicycles/pedestrians are absent, the difference in mean vehicle speed before minus after the warning sign was introduced equals zero.

Inquiry 3) *H_0: μ Before Sign Bikes Present – μ Before Sign Bikes Absent = 0*

Before the warning sign was introduced, the difference in mean vehicle speeds when bikes/peds were present minus when bikes/peds were absent equals zero.

Inquiry 4) *H_0: μ After Sign/Bikes Present – μ After Sign/Bikes Absent = 0*

After the warning sign was introduced, the difference in mean vehicle speeds when bikes/peds were present minus when absent equals zero.

Table 21 summarizes the evidence with regard to the four inquiries described above.

Table 21: Idaho East Inquiry Summary for Changes in Mean Vehicle Speeds

Inquiry/ Null Hypothesis H_0	Change in mean vehicle speed (mph) μ	95% confidence interval (mph)	Two-sided p-value
1) When bikes present, mean vehicle speed before minus after = zero	1.69 mph (slower after)	3.8 mph slower to -0.42 mph faster	0.1160 (insufficient evidence to reject H_0)
2) When bikes absent, mean vehicle speed before minus after = zero	0.57 mph (slower after)	0.109 mph to 1.03 mph	0.0153 (strong evidence to reject H_0)
3) Before warning sign installed, mean vehicle speed when bikes present minus absent = zero	-0.85 mph (faster when bikes absent)	-2.51 mph to 0.82 mph	0.3181 (insufficient evidence to reject H_0)
4) After warning sign installed, mean vehicle speed when bikes present minus absent = zero	-1.97 mph (faster when bikes absent)	-3.26 mph to -0.68 mph	0.0027 (strong evidence to reject H_0)

In terms of Inquiry 1, mean vehicle speeds were estimated to be 1.69 mph slower after the warning sign was introduced. There is weak evidence that this difference differs from 0 mph with a p-value = 0.1160 and a 95% confidence interval of -0.42 mph to 3.8 mph. In other words, there is insufficient evidence against the null hypothesis of no difference in vehicle speed when bikes were present, before and after the warning sign was introduced after controlling for day-to-day variation. We would conclude that there was no difference in vehicle speed in the presence of bikes, before and after.

In terms of Inquiry 2, mean vehicle speeds were estimated to be 0.57 mph slower after the warning sign was introduced. There is strong evidence that this change differs from 0 mph with a p-value = 0.0153 and a 95% confidence interval of 0.109 mph to 1.03 mph. In other words, there is strong evidence against the null hypothesis of no difference in vehicle speed when bikes were not present, before and after the warning sign was introduced after controlling for day-to-day variation. We would conclude that there was a difference in vehicle speed in the absence of bikes, between periods before and after the warning signs were introduced.

In terms of Inquiry 3, mean vehicle speeds were estimated to be 0.85 mph faster when bikes were absent. There is weak evidence that this difference differs from 0 mph with a p-value = 0.3181 and a 95% confidence interval of -2.51 mph to 0.82 mph. In other words, there is weak evidence against the null of no difference in vehicle speed before the warning sign was introduced, in the presence or absence of bikes after controlling for day-to-day variation. We we would conclude that there was no difference in vehicle speed before the warning sign was introduced, between vehicles in the presence or absence of bikes.

In terms of Inquiry 4, mean vehicle speeds were estimated to be 1.97 mph faster when bikes were absent. There is strong evidence that this difference differs from 0 mph with a p-value = 0.0027 and a 95% confidence interval of -3.26 mph to -0.68 mph. In other words, there is sufficient evidence to reject the null hypothesis that the mean vehicle speeds do not differ after the warning sign was introduced, between vehicles in the presence or absence of bikes after controlling for day-to-day variation. We would conclude that there was a difference in vehicle speed after the warning sign was introduced, between vehicles in the presence or absence of bikes.

In conclusion, the model suggests that there is a decrease in vehicle speed after the dynamic warning systems were introduced, and this association is similar whether or not a bike or pedestrian is present. It is important to consider the practical significance of these differences, especially with such a low proportion of total variability being explained.

2.3.9. Idaho Warning Sign Facility Owner Perceptions

On October 21, 2021, WTI conducted an online focus group with the Boundary County Road and Bridge Co-Superintendent and received written responses from the Boundary County Road Foreman who was unable to attend the meeting. Prior to this meeting, the Co-Superintendent had reached out to local partners to get their impressions of the warning system, which were shared during this meeting. A list of 19 questions was sent in advance to contacts that have worked on this project. The discussion is summarized in the five categories below.

2) Observations of bicycle/vehicle interactions

The dynamic warning systems are located on Riverside Road, close to the Bonners Ferry community. One county staff member that drives by the systems several times per week has observed bikes and cars passing the system and noted the Eco-Counter was able to differentiate between the two. A couple that lives nearby and ride their bikes past the system reported they are able to see how the lights start flashing as they ride by and say they work really well for them and the rest of their family. An engineer that works for the City of Bonners Ferry rides bike multiple times per week and felt the systems work well and felt they made it safer to ride out there. A few different people reported they drove out there, saw the lights flashing and then saw bikes ahead further along the roadway.

2) Installation process

There were some glitches with the system not working to start with. When they put the sign up, they had to fix the bracket that holds it to the post. For future installations, the installation crew may need to be willing to tailor the system. When they saw cut the pavement and installed the loop wires, the local store did not have the appropriate grout polymer that was needed. They were able to get a similar product from Sandpoint, Idaho. It may take more than one day to get the system in place and up and running. The instructions and web training were good. If you have a crew and tools, you should be able to take care of the details. The County Road Foreman commented that the installation process was an exciting learning experience.

3) Maintenance and Eco-Counter function

There has not been any maintenance since the systems have been in place. Boundary County staff has tested the system to make sure it is working and uploaded the bicycle count data to the online Eco-Visio system using the Eco-Counter app. They have received approval from county commissioners to budget for battery replacements as needed.

4) Bicycle count data retrieval and online analysis/viewing

Boundary County staff collects bicycle count data from the Eco-Counter once every couple of months and transfers it to the Eco-Visio online platform. They have not used the online dashboard and may follow up with Eco-Counter about training on how to use that.

5) Thoughts on system and advice for others

Boundary County staff would recommend the dynamic warning signs as a tool for other road managers. One staff member commented that people driving rural roads don’t always realize how many bikes may be on road. They aren’t aware of the rock cut on Riverside Road and the flashing light helps raise awareness of bicycles in the area. They added that the system makes sense, looks great, and seems to wake people up as they drive through there. They would install the warning system on another road if they had that situation. Another staff member commented that the dynamic warning sign could greatly improve the safety of bicyclists on certain hazardous roads and that minimal maintenance is required after installation.

3. DISCUSSION AND CONCLUSIONS

This section summarizes results of the warning system reliability and speed analysis, road manager perceptions, challenges, accomplishments, and lessons learned for this pilot project.

Warning Sign Reliability

The warning systems correctly detected bicycles approximately 86 percent to 94 percent of the time, as shown in Table 22. False positives or misidentifications ranged from approximately two percent at Oregon MP 84 to 43 percent at the Idaho East warning sign. This high rate of false positives at the Idaho East sign may be attributed to the low number of bikes present during the study period and a relatively high number of large slow-moving vehicles such as combines, tractors and logging trucks that triggered the system. While the false positives are a high percentage of the Idaho-East sign detections, almost 2400 motor vehicles crossed the loops westbound during this time, demonstrating the system had a relatively low error rate (56/2400= 2.3%) in terms of identifying bicycles from motor vehicles.

Table 22: Summary of Warning System Reliability

Parameter	Colorado Site 1	Oregon MP 84	Oregon MP 78	Idaho East
False positives	76 → 10.8% of 706	7 → 2.2% of 320	31 → 13.0% of 238	24 → 42.9% of 56
False negatives	103 → 14.1% of 733	21 → 6.3% of 334	21 → 9.3% of 227	2 → 3.6% of 34
System reliability	85.9%	93.7%	91.2%	94.1%

False negatives, where the systems missed detecting bicycles, ranged from about 4 percent at the Idaho East sign to 14 percent at the Colorado Site 1. Group riding was common in Colorado National Monument, thus while the Eco-Counter occasionally missed detecting a bike when people rode in groups, there were only four cases when the lights did not flash at all when a bike was present. Each of these consisted of a group of two bikes. Some reasons for the systems not detecting bicycles could include:

- The bicycle did not pass directly over the induction loops. Bikes may not be detected when riding over the outside edge of the loops, or through the three-inch gap between the loops.
- The bicycle was not a standard configuration, such as a tandem bike or a bike pulling a trailer.
- The bicycle was not of expected ferrous composition, such as a carbon fiber bicycle with carbon fiber rims.

In summary, these warning systems displayed relatively high reliability during the study period, correctly detecting bicycles 86 to 94 percent of the time, causing lights to flash to alert drivers to their presence. Eco-Counter provided strong and timely technical support during warning sign installation and expressed interest in continuing to adjust their system algorithms to accommodate site specific conditions.

Warning Sign Speed Analysis summary

The speed analysis indicated mixed results amongst the four sites analyzed. Mean vehicle speeds were reduced for three of the four warning systems analyzed after the warning systems were installed. Table 22 shows the summary of vehicle speed data in mph when bicycles were present, before and after sign installation. At Colorado Site 1 and Oregon MP 84, mean vehicle speeds were reduced when bikes were present after the warning signs were installed by 1.37 and 1.73 mph respectively. The analysis showed strong evidence that these changes in vehicle speed were different than they would be by random chance.

At Oregon MP 78, mean vehicle speeds increased slightly by 0.12 mph from 29.88 to 30 mph when bikes were present after the sign was installed. However, the analysis showed there was insufficient evidence that this change was different than it would be by random chance.

At the Idaho East sign, mean vehicle speeds were reduced by 1.98 mph when bikes and pedestrians were present after the sign was installed. However, the analysis indicated there is insufficient evidence that this change is different than it would be by random chance.

Table 23: Summary of Before and After Vehicle Speeds (mph) when Bicycles were Present

Site	Time period	N	Mean speed	Standard deviation	Minimum speed	Median speed	Maximum speed	85th percentile
Colorado Site 1								
	Before	526	28.41	3.62	13	29	39	32
	After	1239	27.04	3.52	13	27	44	30
	Difference		1.37			2		2
Oregon MP 84								
	Before	173	42.12	7.98	12.17	43.2	63.42	49.03
	After	426	40.39	6.41	14.26	40.83	62.1	46.58
	Difference		1.73			2.37		2.45
Oregon MP 78								
	Before	146	29.88	4.37	11.46	29.66	43.20	33.21
	After	360	30	4.35	13.31	30.11	48.87	33.49
	Difference		-0.12			-0.45		-0.28
Idaho East Sign								
	Before	33	27.85	4.31	21	29	37	32
	After	54	25.87	4.84	12	27	36	31
	Difference		1.98			2		1

Vehicle speed is relatively simple to measure, and the intent of this project was to use speed as a proxy for safety, with the understanding that lower motor vehicle speeds generally result in a safer environment for people riding bikes. However, the analysis suggests that only a small proportion of total variability in vehicle speed (from 1.4% to 3.3%) may be explained by the dynamic warning signs. Thus, speed may not be the best indicator to estimate safety improvements for these warning systems. Other indicators, such as horizontal distance between motor vehicles and bicycles, may provide a better indicator of safety. Due to limitations on video placement, video quality as well as time and budget, such an analysis was not included in this pilot project.

It is not clear that lowering vehicle speeds 1-2 mph will have a significant impact on bicycle safety. Results from a study on vehicle/pedestrian impacts shows that "the average risk of severe injury for a pedestrian struck by a vehicle reaches 10% at an impact speed of 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph. The average risk of death for a pedestrian reaches 10% at an impact speed of 23 mph, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph." (Tefft, B.C. 2011). Figure 28 from the Small Town and Rural Multimodal Networks (FHWA ,2016) provides a visual of these numbers.

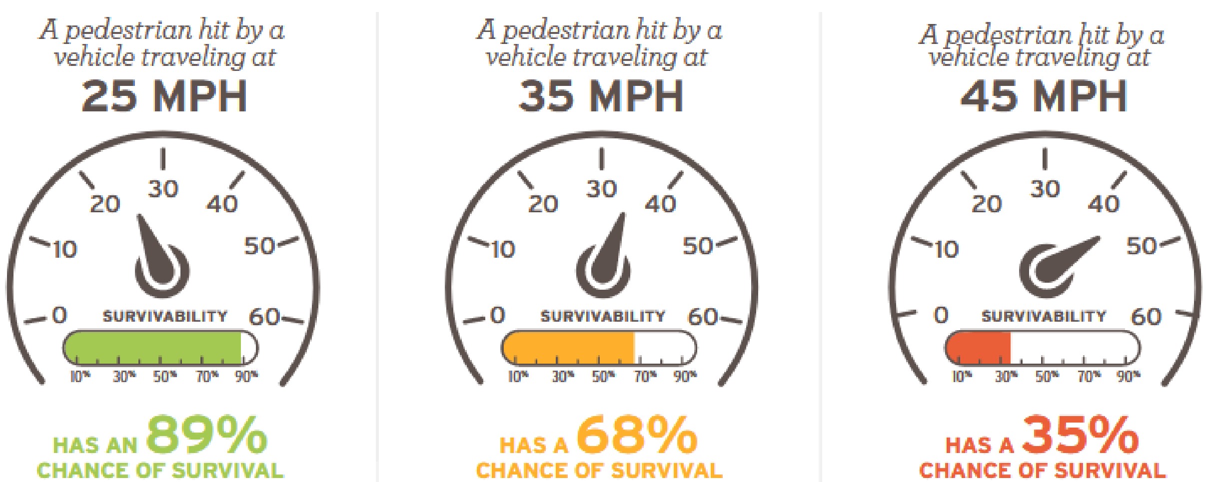

Figure 28: Impact speed and a pedestrian's chance of survival (Tefft, 2011)

Given that motor vehicle speeds tended to be lower when bicycles were present than when there were no bikes in the vicinity, drivers may already be aware of their presence. However, this data analysis suggests that there are many factors that affect motor vehicle speeds, and while the warning system and presence of bicycles have some influence, they do not appear to have a major influence on vehicle speeds.

Facility Owner Perceptions

Colorado National Monument (COLM) staff, Oregon Department of Transportation staff, and Boundary County Idaho staff generally had positive perceptions of these warning systems and received positive feedback from cyclists. Some ODOT staff commented that these systems are probably helpful if there is a specific constraint, such as a tunnel or narrow bridge that would push bikes into the motor vehicle lane. For Oregon Hwy 242, a 15-mile-long curvy road with only two warning signs, at what point do you lose driver attentiveness? Alternatively, the corridor should not be littered with signs. Another ODOT comment was that this warning system looks like school or warning flashers that are always on or on at a set time. The public sees the sign and don’t realize it is triggered by bikes. There has also been feedback from COLM staff wondering if the signs are working. The staff are typically in cars and rarely see the lights flashing, so the assumption is they are not working.

COLM’s Chief Ranger highly recommends this system to others and commented the system is great for blind corners. While ODOT staff would not necessarily strongly recommend this system to others, there is hesitancy to remove dynamic warning signs from the toolbox. The warning signs could be a good tool under the right conditions considering sight distance in limited locations. Boundary County staff would recommend the dynamic warning signs as a tool for other road managers.

3.1. Challenges to Completion and Schedule

The original fall 2018 completion date was delayed for several reasons. Forest fires in Oregon delayed warning system installation by over a year. Uncertainty regarding road construction project schedules at the Colorado and Idaho sites also led to delays in warning system installations. Colorado National Monument lacked staff and equipment resources for sign installation, which was completed by contractors as part of a 2018 FLAP road construction project. Another challenge was managing the video and radar monitoring equipment from a distance, including issues with data download, SD cards and camera views.

3.2. Accomplishments and Lessons Learned

This project combined an existing detection system (inductive loops) with flashing lights to alert drivers to the presence of bicycles along rural roads where motor vehicles and bicycles share a lane. Average daily traffic on these rural roads during the study period were approximately 440 vehicles per day at the Idaho site, 560 vehicles per day in Oregon and 1400 vehicles per day in Colorado (including both traffic lanes). The system’s lights flash only when a person rides a bicycle over the inductive loops, making this system “dynamic.” This project accomplished the deployment of six dynamic warning signs in three different states, allowing road managers direct experience with the systems. Overall, the systems performed with relatively high reliability and received positive feedback from road managers and people riding bicycles. Once initial technical issues were worked out, the warning systems functioned as expected and did not require maintenance within the first one to two years of installation. Ongoing maintenance is similar to other flashing light systems that road crews are typically familiar with. This system performed well at detecting cyclists, differentiating them from motor vehicles, and triggering a warning system for drivers. Based on this pilot project analysis, dynamic warning systems are recommended as a tool that may improve road safety for people bicycling on rural roads. The following advice may be useful to others who are interested in dynamic warning systems.

1. Do not underestimate warning system installation time and effort. These warning systems are large and require a substantial concrete foundation as well as equipment and personnel to install.

2. Be sensitive to different jurisdictions' priorities and resources. ODOT is a transportation agency that had the resources and experience to install and monitor the dynamic warning systems. Land management agencies, such as the NPS or USFS have many responsibilities other than transportation and may not have the resources to procure and install the warning systems. Similarly, rural counties such as Boundary County, Idaho, are likely to have limited staff and capacity to procure and install warning signs. Look for opportunities for warning sign installation as part of planned road paving or construction projects.

3. Pay attention to sawcut and inductive loop configuration details. They are critical for the warning system to detect bicycles and differentiate them from motor vehicles. Require the sawcut contractor, inductive loop installer, and oversight personnel to participate in the Eco-Counter training on installation and setup of the Zelt system. One contractor expressed that they enjoyed learning a new skill and were excited to add inductive loop installation for bicycle detection to their resume.

4. Anticipate time to get specifications correct and some troubleshooting to connect flashing lights with bicycle detection technology. There is currently no "off the shelf" dynamic warning system that we are aware of. The JSF system required an Eco-Counter Connex board to interface with the bicycle detection system. Flashing light systems are typically designed to flash for pedestrian crossings in urban settings. The controllers will likely require re-programming to flash for specific durations such as three or four minutes as with this pilot project. Details such as solar exposure and battery requirements will vary depending on the location.

5. Allow time for equipment delivery. There was a relatively long lead time (6 to 8 weeks minimum) for equipment delivery, which could be exacerbated due to COVID -19 related supply chain issues.

6. If possible, install signs when road is closed to motorized traffic. This can result in time and cost savings if there is no need for traffic control.

7. Warning system equipment costs ranged from about $7600 to $9600 depending on items such as type of flashing light system, battery size, and manual or automatic data transmission for bike count data. This cost does not include installation. (*The Eco-Counter system can be equipped with an Automatic Transmission function that sends data directly to Eco-Counter via GPRS/3G. The data is then processed and analyzed on the online platform Eco-Visio, accessed through a web browser. As of spring 2021, this optional data transmission and web portal had an annual cost of $420.)*

3.2 Contacts

The following personnel were engaged in various parts of this dynamic warning system pilot project and may provide insights for others interested in these systems.

Colorado National Monument

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Oregon Highway 242/ McKenzie Pass Scenic Bikeway

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REFERENCES

Federal Highway Administration (2016). Small Town and Rural Multimodal Networks.

Tefft, B.C. (2011). Impact Speed and a Pedestrian's Risk of Severe Injury or Death (Technical Report). Washington, D.C.: AAA Foundation for Traffic Safety.

Gleason, Rebecca; Allen, Tiffany; Lonsdale, Taylor (2017). Dynamic Warning Systems to Alert Motorists to the Presence of Bicyclists: Implementation Plan for Colorado National Monument

Gleason, Rebecca; Allen, Tiffany; Lonsdale, Taylor (2018). Dynamic Warning Systems to Alert Motorists to the Presence of Bicyclists: Implementation Plan for Oregon Department of Transportation Highway 242/ McKenzie Pass Scenic Bikeway.

Gleason, Rebecca; Lonsdale, Taylor (2019). Dynamic Warning Systems to Alert Motorists to the Presence of Bicyclists: Implementation Plan for Kootenai National Wildlife Refuge.

APPENDIX A: EXAMPLE SCHEMATICS AND SPECIFICATIONS

A.1 Example Specifications for Dynamic Warning Sign

(details will vary according to site location)

Please provide a quote to build sign system as shown in the Figure below with the following specifications:

1. **Sign Posts –**4.5” O.D. threaded steel pipe post and frangible pedestal base. Post and base powder coated black. The post length will be 15’. The sign will require 7’ (84”) between ground and bottom of light, as shown in attached diagram. The post shall include a frangible base. The base shall provide access for wiring and a collar that prevents post rotation.

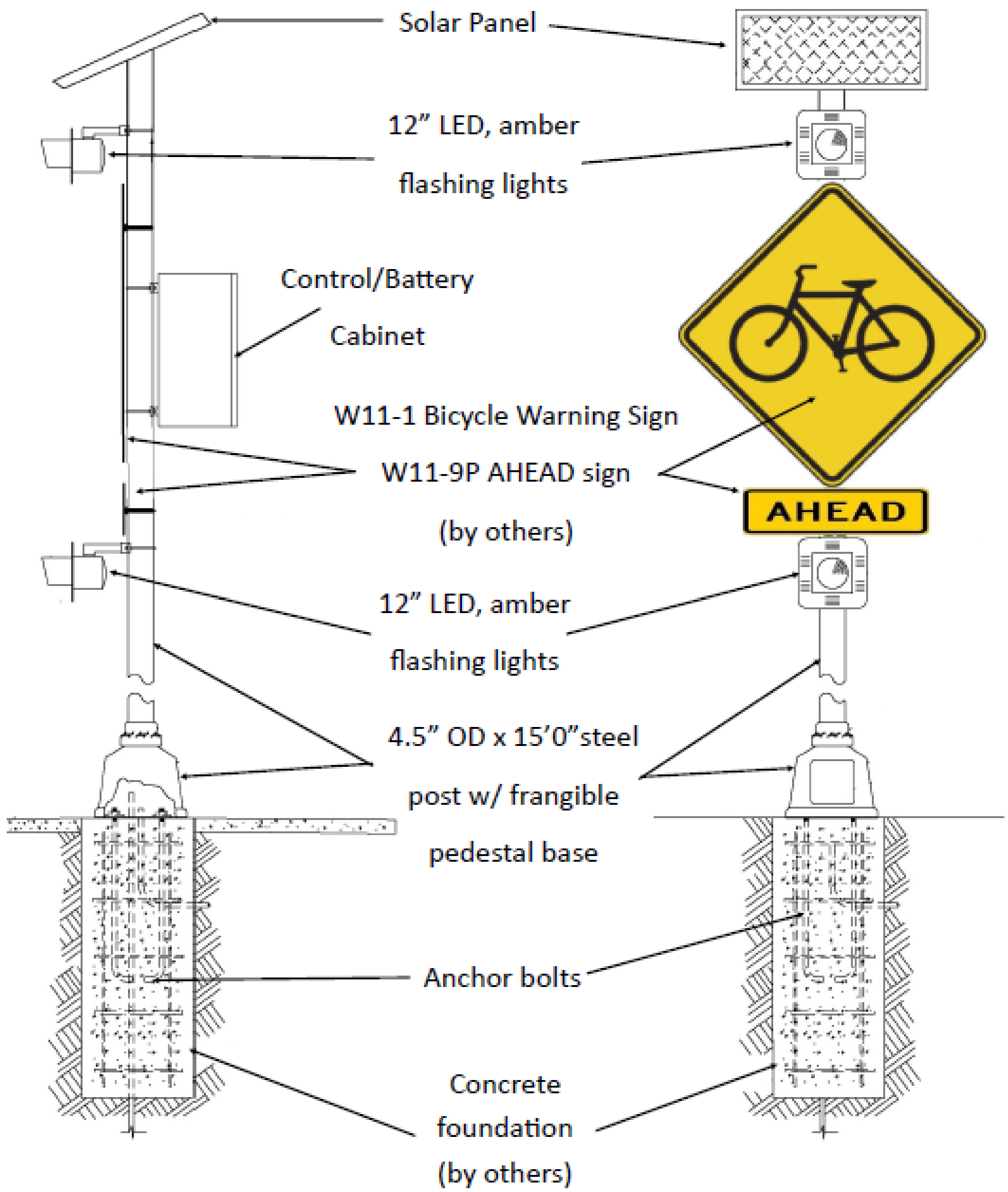
2. **Bicycle and Ahead sign panels and mounting brackets** – W11-1 Bicycle sign 30” x 30”. W16-9p Ahead Signs, 24” x 12”. All hardware required to attach panels to 4.5” post.

3. **Flashing lights –** 12” amber LED flashing lights with black background. Lights shall comply with requirements of the latest MUTCD. The lights will be activated using an EcoCounter Zelt Loop system that detects bicycles. The lights shall have a flash timer that can be adjusted after installation. The flasher timer must have the capability to reset each time a bicycle triggers the lights. Thus, if the lights are set to flash for 3 minutes when a bicycle crosses inductive loops, and then another bicycle comes by a minute later, the lights will reset to flash for 3 more minutes. The flashing light duration must re-start every time a bicycle passes over the loops. All equipment and hardware required to connect the lights to the solar/battery system and the signpost shall be included.

4. **Solar panel/battery system to power flashing lights and counter system** – Solar panel/battery systems and all equipment and hardware required for connecting the solar panels and the battery system and for fastening these to the sign pole shall be included. We are specifying a minimum of X Amp hours of battery for this system. The bidder shall determine the necessary wattage of the solar panel based on the following information regarding location and activation time for the flashers and the power demand of the proposed system.

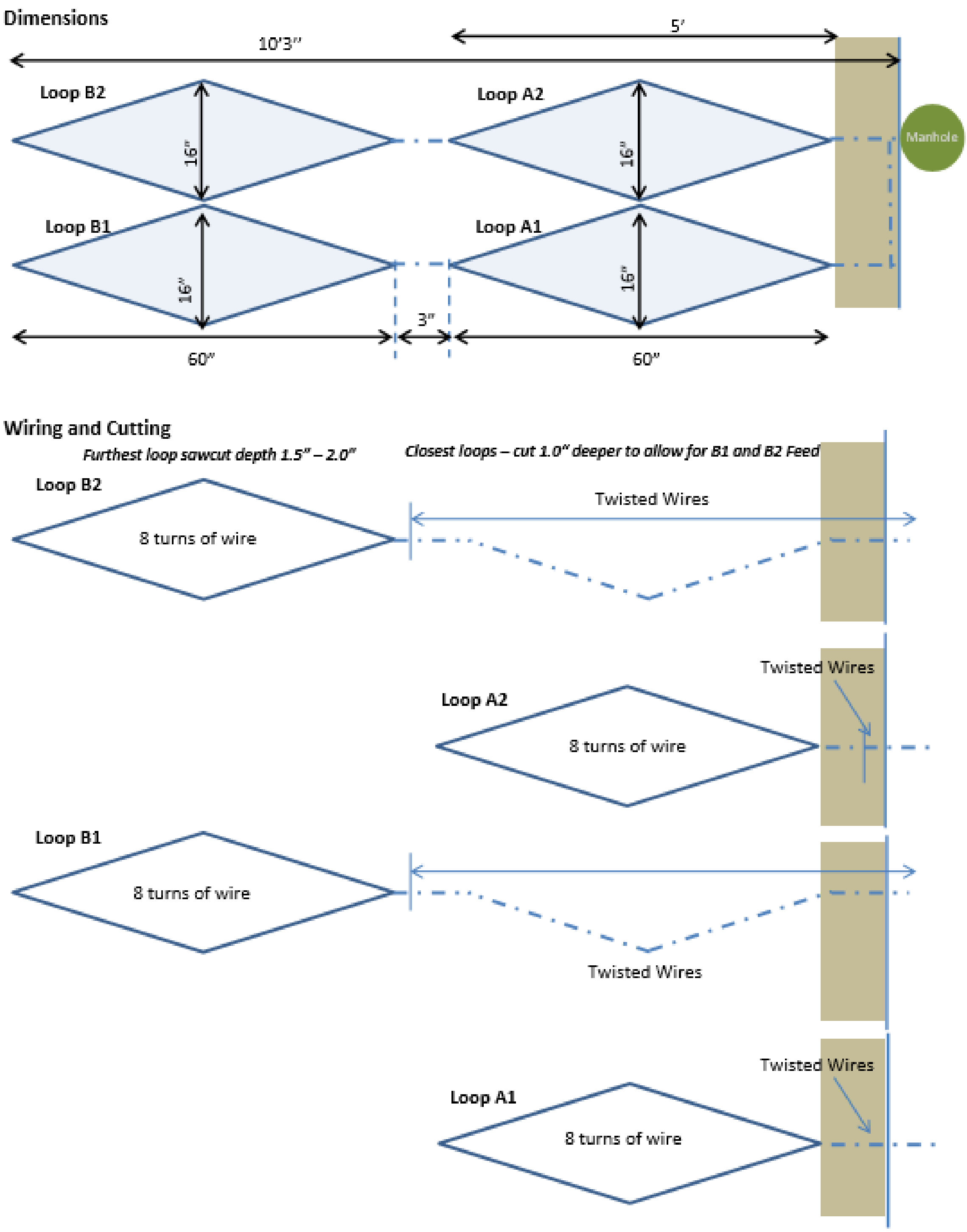
These signs will be located on Riverside Road in a rural area just west of Bonners Ferry Idaho. This solar system must be able to power the two flashing LED lights. This system is designed to flash when people on bicycles ride over inductive loops in the pavement. The flashing lights are anticipated to be active for 3 minutes each time they are activated. We anticipate as many as 40 bicyclists each day so the system could be active for 120 mins each day from June through mid-October.

In addition to the lights, the solar system will power a 4- loop Eco Counter Zelt system with dry contact output from the ZELT. The ZELT sensor needs very little power (under 0.1 W), but this power needs to be available constantly. On average, the energy consumption of the counter system is less than 1 Wh per day, which is likely is a lot less than what's needed for the flashing sign itself. In order for the Eco Counter to be powered from the solar panel, there must be a regulator/accumulator system built in the solar power supply unit so that it can deliver constant power (so that the system can still work at night or in poor weather conditions).

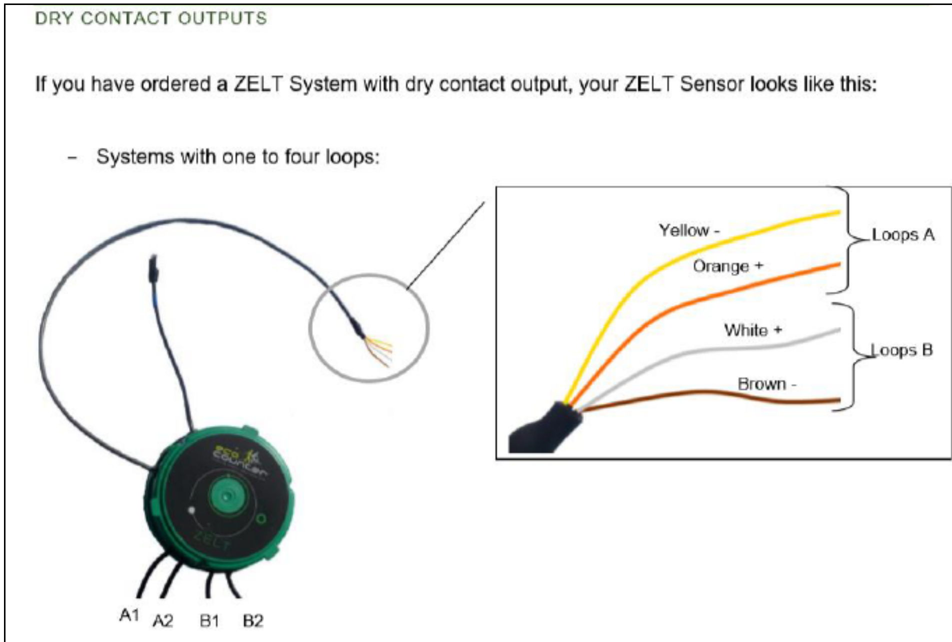


*Note that the control/battery cabinet may be integrated into the solar panel at the top of the sign, rather than mounted behind the sign panel, depending on the equipment type and vendor.

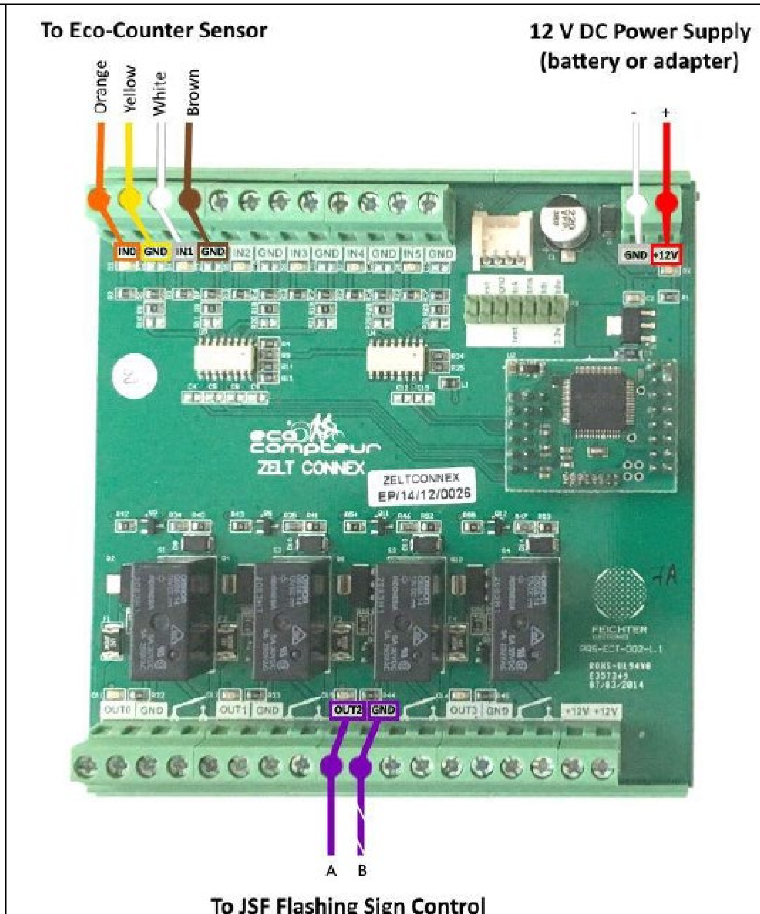
A.2 Plan view of inductive loop layout for bicycle detection (courtesy of Eco-Counter)



A.3 Eco-Counter Zelt Sensor Wires and Connex Board Wiring Diagram

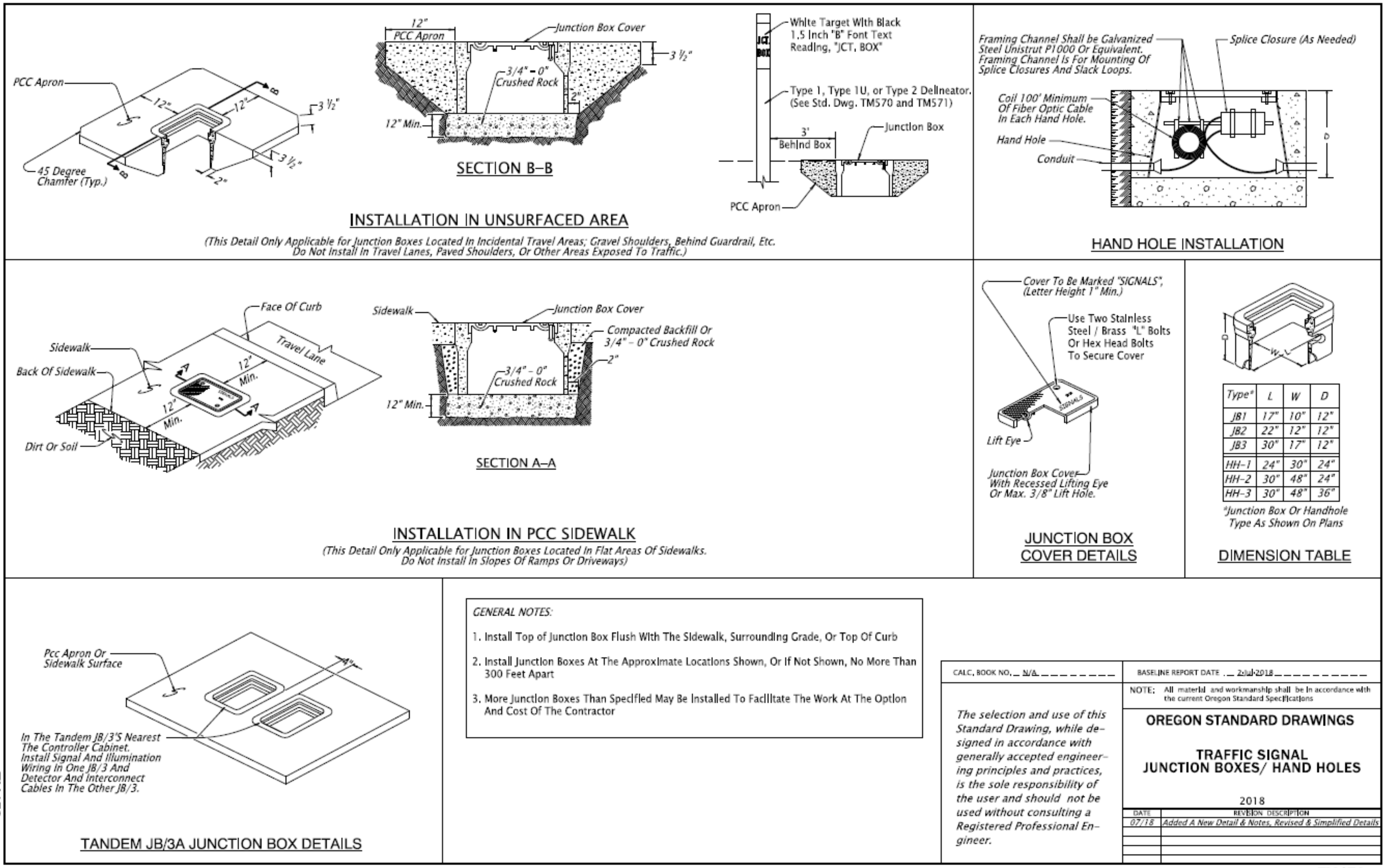


Eco-Counter Zelt Sensor with wiring



Eco-Counter Connex Board Wiring with JSF solar powered flashing beacons (courtesy of Eco-Counter)

A.4 ODOT Traffic Signal Junction Boxes/ Hand Hole Detail (TM472)



Type*	L	W	D
JB1	17"	10"	12"
JB2	22"	12"	12"
JB3	30"	17"	12"
HH-1	24"	30"	24"
HH-2	30"	48"	24"
HH-3	30"	48"	36"

*Junction Box Or Handhole Type As Shown On Plans

GENERAL NOTES:

1. Install Top of Junction Box Flush With The Sidewalk, Surrounding Grade, Or Top Of Curb
2. Install Junction Boxes At The Approximate Locations Shown, Or If Not Shown, No More Than 300 Feet Apart
3. More Junction Boxes Than Specified May Be Installed To Facilitate The Work At The Option And Cost Of The Contractor

Effective Date: June 1, 2019 – November 30, 2019

TM472

A.5 ODOT Sand Pocket Loop Wire Entrance Detail (DET4428) and Photo

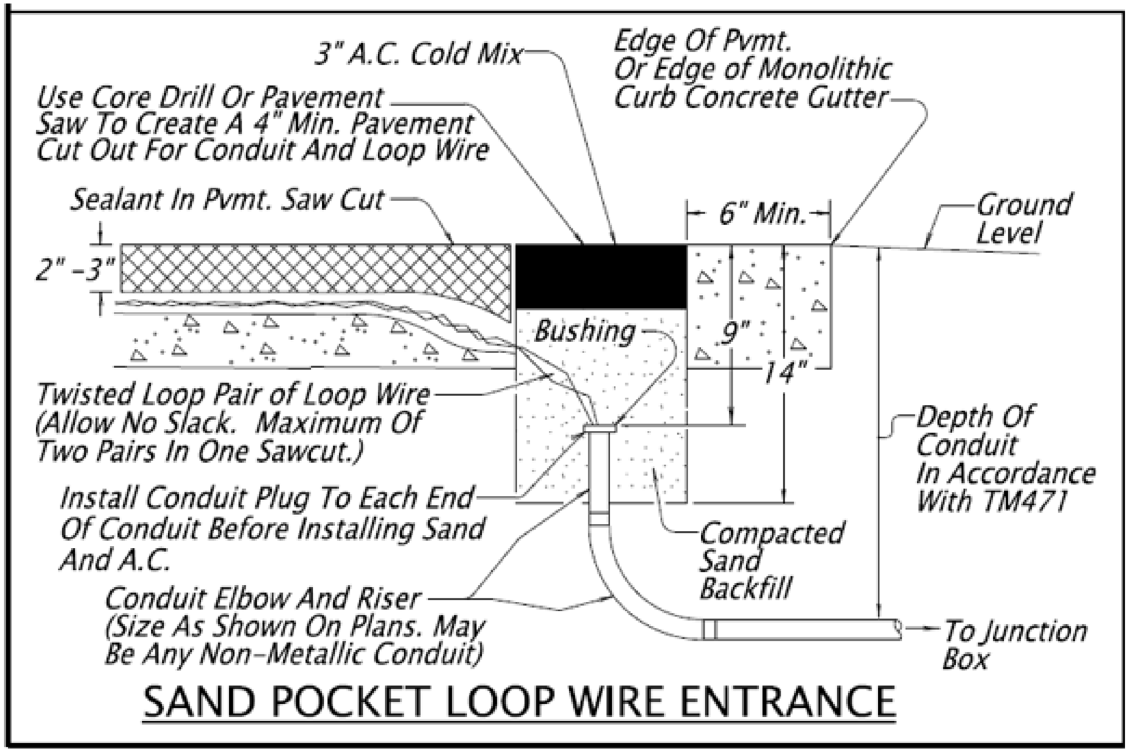


Photo of sand pocket before the sand and cold mix is added. Notice the pavement cut near the top of the picture where the wires come in from the roadway.

A.5 ODOT Warning Sign Pedestal Installation Detail (DET4431)