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LOCAL
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BOARD

Guidelines for Using Intelligent Warning Devices

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The purpose of this reference guide is to provide local agency staff a resource on four intelligent warning devices (active warning signs) that includes a general explanation on the use of the sign and their effectiveness, recommended installation protocols, alternative countermeasures to consider and maintenance considerations. With this guide, agency staff can identify whether implementation is warranted and further provide sourced responses to citizen's requests for them. The four intelligent warning devices covered in this reference guide includes:

- LED Enabled Signs,
- Radar Speed Feedback Signs,
- Rectangular Rapid Flashing Beacons, and
- Dynamic "No Turn on Red" Signs.

Nevertheless, the information provided must be used with engineering judgement. Due to the differences between urban vs. rural environments, city vs. county agencies and staff availability, there is no one size fits all approach. This document provides general guidance that should be modified to meet each agency's needs.

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TABLE OF CONTENTS

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The purpose of this reference guide is to provide local agency staff a resource on four intelligent warning devices (active warning signs) that includes a general explanation on the use of the sign and their effectiveness, recommended installation protocols, alternative countermeasures to consider, and maintenance considerations. With this guide, agency staff can identify whether implementation is justified and further provide sourced responses to citizen's requests for them. For additional guidance on responding to citizen requests, see the LRRB Report - Addressing Citizen Requests For Traffic Safety Concerns. The four intelligent warning devices covered in this reference guide includes:

- LED Enabled Signs,
- Radar Speed Feedback Sign,
- Rectangular Rapid Flashing Beacon, and
- Dynamic "No Turn on Red" Sign

The information provided must be used with engineering judgement. Due to the differences between urban vs. rural environments, city vs. county agencies and staff availability, there is "no one size fits all" approach. This document provides general guidance that should be modified to meet each agency's needs. Each intelligent warning device should be individually investigated and right-sized for the location to ensure the safety of all modes of transportation based on each agencies' policies. Further, prior to implementing a device, alternative countermeasures and increased or improved conspicuity of a sign should be considered. See Section 2A.15 Enhanced Conspicuity for Standard Signs of the MN MUTCD (2011) for the 12 Enhanced Conspicuity of Standard Signs, particularly the use of a warning beacon as described in Section 4L.03 Warning Beacon.

Maintenance Considerations for Intelligent Warning Devices

The Minnesota's Best Practices of Traffic Sign Maintenance and Management Handbook (Part D) recommends that agencies develop written practices or procedures related to signing activities, including maintenance and management, to limit agencies' liability when applying signs. The practice/procedure can aid agencies with defense against claims of negligence by clearly stating when it is appropriate to install intelligent warning devices at particular locations and when/how maintenance is conducted. In simple terms, plan the work and work the plan.

The practice/procedure should clearly state routine maintenance processes and procedures to ensure continued operation of all electrical and electronic systems. At a minimum this should include an annual inspection and verification of proper system operation. In addition, agency staff should have sufficient training to operate and maintain the device. At the time of purchase, agencies can consider obtaining training from the manufacturer's representative and include any costs for this training in the purchase price of the device.

Agencies should also determine and document their response (i.e. 24-hour, 7-days per week or within 1-2 business days, etc) for various outage scenarios relating to the various intelligent warning devices they may choose to install.

List of Considerations for any Solar Powered Systems

- Agencies should plan for replacement of solar panels at the end of their effective life. The expected life of a solar panel is 25 to 30 years.
- Annual review of solar panels should include cleaning of the surface and testing the charging output in compliance to the manufacturer's instructions.
- Most solar powered systems use maintenance free batteries. Planning for the replacement of these batteries is necessary to ensure proper system operation. Absorbed Glass Mat (AGM) batteries are commonly used and have a life expectancy of 5 to 7 years.
- Annual review of batteries should include testing the output for compliance with the manufacturer's specifications.
- Due to battery failure and Minnesota's climate, some challenges exist when using solar without a hard wired back up. Consider when it is appropriate to use solar vs. hard wiring alone/backup.
- Agencies should also have trained staff to maintain the standard electrical-powered device (high-voltage). If not, they may want to consider installing solar-powered devices (low-voltage) or consider developing a relationship with a vendor to provide routine and emergency maintenance services.
- It is always recommended to consider current MUTCD guidance before any new sign is placed.

Inter-Agency Collaboration to Consider Prior to Installing Intelligent Warning Devices

No agency wants to apply a solution that isn't defensible and sustainable. Therefore, prior to installation, agencies should consider potential impacts and alternative practices followed by each jurisdiction that share responsibilities of the roadway. Developing a uniform criteria and setting the precedent to understand the system, as a whole, will help to apply these devices systematically versus reactively across Minnesota.

INTELLIGENT WARNING TRAFFIC SAFETY DEVICE

There are many intelligent warning devices that citizens request. This reference guide will focus on:

LED Enabled Sign

Radar Speed Feedback Sign

Rectangular Rapid Flashing Beacon

Dynamic “No Turn on Red” Sign

This section will provide information about each intelligent warning sign. For each sign, the following are summarized:

- General definition
- Considerations/Challenges
- First Step - Good Engineering Judgment
- Alternative Countermeasures (Other Solutions)
- Maintenance Considerations
- Other Consideration
- Educate-Encourage-Enforce (Resources)

LED ENABLED SIGN

(REGULATORY AND WARNING)

General Definition:

- LED enabled signs include embedded light emitting diodes (LEDs) within a sign's symbol, legend, or border to increase its conspicuity. [(1)]
- May be used on regulatory and warning signs
- **Purpose:**
  - Regulatory Signs - To improve driver compliance and safety by enhancing driver awareness through improved conspicuity.
  - Warning Signs - To enhance visibility and recognition for drivers, especially under low-light or low-visibility conditions , like curves.[(2)] LED enabled signs may also be activated when a warning is applicable (for example at a fire station access, RRFB, and other periodic conditions) to further enhance driver visibility.
- **Safety:** Replacing a standard stop with a flashing LED STOP reduces 41.5% of angle crashes. (Effectiveness: .585 CMF)
- **Compliance:**
  - Adding LED STOP signs did not substantially change driver reaction to slow their vehicles as they approached the intersections – reported reductions were in the range of 1 to 3 miles per hour with slightly higher reductions at night. [(8)]
  - The LED STOP sign did not change the fraction of vehicles making complete stops at the intersections (when minor approach drivers did not encounter opposing vehicles on the major approaches). [(8)]

Considerations/Challenges

- Treatment is applicable for both regulatory and warning signs and can be implemented: [(2)]
  1. At locations with sight visibility limitations (horizontal curves, dusk/dawn glare, etc.)
  2. At locations with documented problems of drivers failing to recognize an intersection
  3. At STOP signs to increase the rate of vehicles stopping and to avoid drivers failing to detect the STOP sign.
- See MnDOT APL/QPL for Added Emphasis signs
- According to the 2009 MUTCD, the use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs.
- LED enabled signs can be set to flash or operate in a steady mode when the condition is applicable (fire station entrance, pedestrian activated crossing for example), when a vehicle approaches or on continuously. However, overuse of LEDs will reduce a driver's response/ compliance.
- LEDs must be red or white if used with Stop (R1-1) or Yield (R1-2) signs, white if used with other regulatory signs, and white or yellow if used with warning or school signs. [(3)]
- If used, the LEDs shall be the same color as the sign legend, border, or background. If flashed, all LED units on an installation shall flash simultaneously at a rate of more than

50 and less than 60 times per minute. The uniformity of the sign shall be maintained without any decrease in visibility, legibility, or driver comprehension during either daytime or nighttime conditions. [3]

- Individual or groups of LEDs should not be placed in a background area of a sign except for STOP and YIELD signs, which permit LEDs within the border or within one border width within the background of the sign. [3]
- Consider the various design alternatives dependent on cost and maintenance from the Intersection Safety Technologies, Quick Reference Guide, 2016. [5]
- Crashes are more likely to occur at rural intersections when a previous stop has not occurred within 5 miles of an approach with a stop or yield condition. Therefore, LED stop signs may be advantageous at such locations.
- Prior to placing LED enabled signs, consider residential impacts.

First - Step Good Engineering Judgment

LED enabled signs should be used judiciously and not implemented everywhere. Agencies should consider alternative countermeasures first. According to the MnDOT Traffic Engineering Manual (Chapter 6-5.03.02 Flashing LED STOP and YIELD Signs (R1-1 and R1-2), July 2022), LEDs should be limited to locations where at least two of the following criteria exist. Other agencies have established policies with three or more of the following criteria exist:

- Limited visibility on approach to an intersection or roadway condition requiring warning should be determined by the sight distance criteria. (Reference the current MnDOT Traffic Engineering Manual Warrants).
- A history of crashes documented to be caused by a failure to stop or adherence to warning,

and deemed preventable by implementation of conspicuity improvements.

- At a rural junction of two or more high speed trunk highways to warn drivers of an unexpected crossing of another highway.
- At a rural junction of a trunk highway and a local road which has no STOP controlled intersection within five miles.

Sound engineering judgment can be informed by evaluation of crash reports to confirm that they are failure to stop vs. failure to yield.

Alternative Countermeasures (Other solutions)

When implementing alternative countermeasures, agencies should coordinate with MnDOT and others on multi- jurisdictional roadways to avoid delays. The following alternative countermeasures should be considered prior to implementing a LED enabled sign: (4)

- Install pavement marking stop bars and messages like STOP AHEAD in advance or STOP at stop bar location
- Install an advanced warning sign on approach to the intersection or warning condition
- Increase the size of the existing signage
- Install a second sign of equal or lesser size on the left-hand side of the road (see MN MUTCD (2011) Section 2A.15 and 2B.3 regarding sizes of stop signs.)
- Add one or more red or orange flags (cloth or retroreflective sheeting) above a standard sign, with flags oriented at 45 degrees to the vertical.
- Add red flashing beacons.
- Install in-lane rumble strips on approach to the intersection according to Chapter 4-4.02 of the MnDOT Road Design Manual.

Maintenance Considerations

- Lighting elements for illuminated signs (e.g. LED-embedded signs) should be replaced on a regular maintenance schedule and should include routine inspection. MUTCD (2009), Section 2A.22 (2)
- LED's have lower power usage and thus can be deployed at most locations using solar power.
- See the "List of Considerations for any Solar Powered Systems" paragraph under the Introduction Section of this Reference Guide for additional maintenance tips on solar panels and batteries.

Educate-Encourage-Enforce

RESOURCES/FOOTNOTES

1. LED Units Within a Regulatory or Warning Sign, ITE
2. Embedded LEDs in Signs (2009) FHWA
3. MUTCD Section 2A.07 Retroreflectivty and Illumination (2009)
4. Technology Enhanced Traffic Control Policy, City of Elk River (Apendix A)
5. Intersection Safety Technologies, Quick Reference Guide, (2016) LRRB
6. Estimating the Crash Reduction and Vehicle Dynamics Effects of Flashing LED Stop Signs, (2014) LRRB
7. MnDOT Traffic Engineering Manual Chapter 6-5.03.02 Flashing LED STOP and YIELD Signs (R1-1 and R1-2) for more information on alternatives and installation, maintenance, and replacement considerations.
8. County Road Safety Plan - LED Stop Signs One Pager, (2017) MnDOT
9. MN MUTCD (2011)

RADAR SPEED FEEDBACK SIGN

General Definition

- A radar speed feedback sign is a speed-measuring device, which consists of loop detectors or radars, and a message sign that displays feedback to those drivers who exceed a predetermined speed threshold. The feedback can include displaying the driver's actual speed, showing a message such as SLOW DOWN, or activating some warning device, such as beacons or a curve warning sign. [1]
- **Purpose:** To reduce vehicle speeds, and therefore crashes, by giving drivers who are traveling over the posted or advisory speed a targeted message. [1]
- **Safety:** Guidance from the County Road Safety Plan Updates, says a radar speed feedback sign can result in approximately a 5-7% reduction in crashes on urban segments. On two-lane rural horizontal curves, a radar speed feedback sign may result in a 5% crash reduction (Effectiveness: .95 CMF)
- **Compliance:** A study measured analyzed sustained posted speed limit compliance at rural, horizontal curves over a five-year period. Results indicated that continuous use of radar speed feedback signs provides prolonged speed management where applied resulting in a mean speed change that was statistically significant, further reducing crashes. [2]
- A FHWA study indicates experiencing changes in the 85th percentile speed of 3 mi/h or more at the point of curvature, with the majority of sites having a decrease of 2 mi/h at the center of the curve resulting in a reduction in lane departures on two-lane rural curves with a high crash history. [1]

Considerations/Challenges

- Installation can be at horizontal curves or used in conjunction with traditional speed limit signs, where speed changes occur at transition zones and should be mounted on the same post as the speed limit sign.
- When activated, the sign display shall give drivers immediate feedback on their individual driving speed. [4] That said, it should not include strobe lights (MnMUTCD Section 2A.15 (2011)).
- When traveling above the posted speed limit, the sign shall rapidly flash or have other dynamic elements. [4]
- When installed in association with school speed zones, the speed feedback signs shall operate only when the school speed zone is in effect. [4]
- The installation shall not interfere with the visibility and general effectiveness of any other signs in the area. [4]
- Field placement should consider the sight-line. Installation on curvy roads are challenging.
- When using the device in a pair, ensure that they don't interfere with each other.
- Prior to placing a radar speed feedback sign, consider residential impacts.

- See MnDOT APL/QPL and MN MUTCD for product requirements. 2B Regulatory Signs and 7A for Traffic Controls for School Areas

First Step - Good Engineering Judgment

When deploying a radar speed feedback sign, agencies should use their engineering judgment to consider how many criteria to satisfy. The following criteria is a combination of recommendations by FHWA and practices used by other agencies: (Please see Appendix A for the City of Elk River's Policy) (3)

- The 85th percentile speed exceeds the posted speed limit by at least 5 mph during the time period of concern.
- A speed transition area exists.
- The area of interest is within the vicinity of a school or other high pedestrian traffic area.
- The posted speed is 40 mph or less (Also see MnDOT's reference on Vehicle Speed Feedback Signs: Buyer and Installation Guide that notes up to 45 mph or less)..
- Repeated lane departures and crashes exist, which is linked to excessive speed at the location.
- The area of interest is where the posted speed limit transitions and decreases by at least 10 mph.

See Appendix B - Effective Deployment of Radar Speed Signs (Location Specific Guidance) by FHWA for additional information.

Alternative Countermeasures (Other solutions)

Prior to, or in lieu of, implementing a radar speed feedback sign, consider the following:

- Installing traffic calming techniques such as raised pedestrian crossings, speed tables (or benches), and median planters.

- Installing bumpouts and speed tables (consider impacts to bicyclists).
- Deploying enhanced, targeted law enforcement.

Maintenance Considerations

- The most significant problem experienced by agencies was maintenance related to vandalism [(6)].
- It is recommended that preventative maintenance be performed on the signs at least twice a year, including cleaning, calibrating, checking the clock and bulbs, and removing branches or other items that could shade the solar panels [(6)].
- Routine checks to confirm accuracy of speeds are recommended. This can be completed by a simple speedometer comparison.
- See the "Requirements to Consider for any Solar Powered Systems" paragraph under the Introduction Section of this Reference Guide for additional maintenance tips on solar panels and batteries.

Other Considerations

- Meet with the citizen(s), elected officials, or group(s) and identify vehicle speeds using a radar gun to determine if it is only a perception, not an issue.
- If speed is the key issue, install a temporary speed trailer to monitor traffic speeds. Speed trailers can bring attention to drivers that their speeds are too high.
- Based on a Minnesota deployed survey, some agencies implement a cost share policy with schools to distribute the responsibilities of material, installation, and maintenance costs. (See Appendix A for examples from Elk River and Otter Tail.

Educate-Encourage-Enforce

VIDEOS:

- Speed Perception – City of Crystal – Video shows a vehicle driving at different speeds on neighborhood streets. This shows the difficulty in determining the speeds of vehicles based on just the eye test.
- Speed Limits: Why do we have them? – LRRB – Shows the research behind setting speed limits and the need for consistency. Also shows that the design of the roadway will influence speeds more than a speed limit sign.
- Setting Speed Limits: – Video shows how to determine speeds limits for roadways.

RESOURCES/FOOTNOTES

1. Spotlighting Speed Feedback Signs FHWA (2016)
2. Long-Term Effectiveness of Radar Speed Feedback Signs for Speed Management. Jue Matthew and James Jarzab. ITE Journal (2020)
3. Technology Enhanced Traffic Control Policy, City of Elk River (Appendix A)
4. MnDOT Approved/Qualified Product List Information for Vehicle Speed Feedback Signs (2022)
5. MN MUTCD (2011)
6. Effectiveness Deployment of Radar Speed Signs. Western Transportation Institute (2010) P. See Appendix B for the Location Specific Guidance from the full report.

RECTANGULAR RAPID FLASHING BEACON

General Information

- The Rectangular Rapid Flashing Beacon (RRFB) is a rectangular shaped high intensity light-emitting-diode (LED) based indication with yellow flashing lights by a pedestrian push button for a predetermined time approximately equal to the expected pedestrian crossing time.[4]
- **Purpose**: To enhance pedestrian conspicuity and increase driver awareness of the presence of a pedestrian at uncontrolled, marked crosswalks. [7]
- **Safety**: RRFBs can reduce crashes up to 47% for pedestrian crashes. Motorist yielding rates at RRFB locations were observed to be as high at 98 percent at marked crosswalks, but varies depending on the location, posted speed limit, pedestrian crossing, distance, one- versus two-way road, and the number of travel lanes. [4] (Effectiveness – 0.53 CMF)

Considerations/Challenges

- Research findings indicate that stop compliance may be sustained over time with consistent application. To achieve consistent application, see the next section for more information.
- Although MUTCD permits an additional RRFB installation on an approach in advance of a crosswalk if adequate sight distance cannot be achieved, recent research findings indicate that a secondary RRFB may not be appropriate. Instead the use of an advanced LED warning sign activated only when the RRFB is active was successful to reduce or eliminate driver confusion.
- An RRFB should not be used for crosswalks across approaches controlled by YIELD signs, STOP signs, traffic control signals, or pedestrian hybrid beacons. See STEP Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations on locations over 40 mph. Some agencies have installed these devices in front of yield control locations, so that the yield is separate from the crossing.
- RRFBs require a power source. The most common application is battery powered with a solar panel to recharge the battery but may also be wired to a traditional power source. See previous section on List of Considerations for any Solar Powered Systems in this report.
- If a median refuge island cannot be constructed on a 2-way street and/or the pedestrian volume falls above the RRFB limit, agencies should review the geometry and consider alternatives.
- RRFBs are not appropriate in locations where there is a combination of both high traffic volumes and high pedestrian volumes. [8]
- RRFBs can also accompany school or trail crossing warning signs. [4]
- To ensure adequate sight distance of drivers and pedestrians, see the MN MUTCD for guidance on roadway design, location geometry and street lighting.
- Agencies should use their discretion with newer technology (add-ons to these devices). That said, CAV technology is continuing to evolve and new elements may be added to the device.

- MnDOT is developing Rapid Rectangular Flashing Beacon Design Standards (expected to be made available May 2023).

First Step - Good Engineering Judgment

Minnesota agencies must prepare an Interim Approval Reporting Form (IA-21, Ped-Actuated RRFBs at Uncontrolled Marked Crosswalks) available on MnDOT's website. Such approvals allow the interim use, pending official rulemaking, of a new traffic control device, a revision to the application or manner of use of an existing traffic control device, or a provision not specifically described in the MUTCD. To determine if an RRFB is appropriate, each crossing location requires a thorough assessment and engineering judgment. Further, alternative considerations should also be assessed prior to installing an RRFB. Agencies should also consider documenting their review process and all considerations for pedestrian safety enhancement at the location. See FHWA's STEP Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations and an example process guidance below from Dakota County.

Field Review and Preliminary Data Collection

Analyze readily available data and leverage local knowledge to understand existing conditions and potential issues. This step should take less than 30 minutes and will determine if the crossing is acceptable for additional review below.

Data Collection and Analysis

- Identify the crossing location.
- Collect roadway geometric and configuration data.
- Collect traffic and operational data.
- Collect multimodal data.

Evaluate Candidate Locations

Evaluate the location using the flowchart (Appendix C) and perform a high-level review to determine if a crossing enhancement is appropriate:

- If the crossing does not meet one or more criteria in the flowchart, no action is recommended. Agencies should consider directing multimodal users to the nearest marked crossing.
- If the crossing location is appropriate for consideration of infrastructure enhancements , proceed to the engineering review process.
- MN MUTCD recommends engineering studies that could include the following:
  - Recommended Volumes: less than 12,000 vehicles per day. [2] less than 400 pedestrians per hour. [8]
  - Recommended speeds: less than 40 mph However, 40 mph or higher at lower ADTs may be considered on two and three lane roads. [9]
  - Geometric assessment. Consider the existing roadway configuration and potential site distances for both approaches/how to reduce conflict points. Minimum sight distance: 325 ft using a stopping sight distance formula for 40 mph on a flat surface (Wright Co). Other sight distances will need to be calculated accordingly for various grades.
  - Crossing enhancement evaluation includes the consideration to the number of lanes to cross, daily traffic volumes and posted speed limits.
  - Review of other potential minor/ major enhancements outside of an RRFB.

Alternative Countermeasures (Other solutions)

Prior to installing a RRFB, consider other potential enhancements. Use your engineering judgment to evaluate the conditions and identify whether a certain alternative safety enhancement is appropriate to increase pedestrian safety. Studies have shown that in some cases, pedestrian safety decreases at uncontrolled marked crosswalks. See NCHRP 500 "A Guide for Reducing Collisions Involving Pedestrians" for more information. Alternative countermeasures might include:

1. High visibility crosswalk markings, adequate nighttime lighting levels, cross warning signs
2. Install an advanced warning sign on approach to the crosswalk
3. Increase the size of the existing signage.
4. Install a second sign of equal or lesser size on the left-hand side of the road (See MN MUTCD)
5. Geometric changes (tighten curb radius to shorten crossing distances, such as a Curb Extensions/bump outs
6. Additional traffic calming measures or potential to lower speed limits.
7. Add one or more red or orange flags (cloth or retroreflective sheeting) above a standard sign, with flags oriented at 45 degrees to the vertical.

8. Add a strip of retroreflective material to the sign support.

9. Add an in-street Pedestrian Crossing sign. Under certain conditions, more substantial enhancements may be necessary. See FHWA STEP Guide for Improving Pedestrian Safety at Uncontrolled Locations for more information.

Maintenance Considerations

- Internal components may need troubleshooting and/or to be replaced periodically.
- If solar panels are used, batteries will last between five to ten years.
- Yearly maintenance includes visual inspections of rust, damage, the LED window, and mountings for security and stability.
- See the "Requirements to Consider for any Solar Powered Systems" paragraph under the Introduction Section of this Reference Guide for additional maintenance tips on solar panels and batteries.

Other Considerations

- Based on a Minnesota deployed survey, some agencies implement a cost share policy to distribute the responsibilities of material, installation, and maintenance costs. (See Appendix D for an example).
  - **Example:** If the RRFB is vulnerable to being defaced, consider including a resolution stating that the community would be responsible for 50% of the replacement cost.
- Some agencies also conduct outreach to educate the public and law enforcement officers on their purpose and use. (FHWA)
  - **Example:** Washington County includes a warning sign on the RRFB to educate the public on their use. See image on page 11 for Dakota County's sign.

Educate-Encourage-Enforce

VIDEOS:

- RRFB Video – shows the potential improvement in crosswalk compliance with an enhanced crosswalk
- RRFB on Campus – shows the potential improvement in crosswalk compliance with an enhanced crosswalk

RESOURCES/FOOTNOTES

1. "Rectangular Rapid Flash Beacon" in PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System. FHWA, (2013).

2. Pedestrian Crossings: Uncontrolled Locations – Provides a flowchart for best practices and provides effectiveness for specific uncontrolled crossing treatments.

3. Minnesota Guidance for installation of Pedestrian Crosswalks on Minnesota State Highways

4. FHWA Proven Safety Countermeasures: RRFB

5. NCHRP Research Report 841 Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments, (2017).

6. Dakota County Pedestrian Crossing Safety Assessment Flowchart (2022) (Appendix C)

7. Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations. FHWA (2018)

8. Pedestrian Crossing Treatment and Installation Guidelines, City of Boulder, CO.

DYNAMIC "NO TURN ON RED" SIGN

General Definition

- Blank out signs that illuminate when the turn-on-red is prohibited.
- **Purpose:** To prohibit right turn movements on red at signalized intersections to mitigate conflicts stemming from motorists basing turning decisions on gaps in conflicting traffic rather than looking for crossing pedestrians[1]. The device may also be used for additional purposes other than pedestrian protection. For example, at transit corridors and at signalized intersections with a railroad.
- **Safety:** Can help reduce crashes involving right turns with limited sight distance towards pedestrians and bicyclists.

Considerations/Challenges

- Additional enforcement may be necessary to improve compliance, and enforcement may be more difficult with a blank out sign relative to a static sign.[1]
- Implementation may lead to an increase in right turn on green conflicts with pedestrians. A best practice to install a leading pedestrian interval (LPI) and/or the Dynamic "No Turn on Red" Sign is to buffer pedestrians in the crosswalk before drivers have the green indication to turn right.[1] Some agencies have also used Dynamic "No Turn on Red" signs at a dual left turn location activated by a pedestrian push button.
- Could cause intersections to experience an increase in motor vehicle delay, making it more challenging to implement where vehicle volumes are higher. [1]
- Another consideration to be evaluated is pedestrian movements at parallel crosswalks conflicting with a vehicular turning movement on a green light.

First Step - Good Engineering Judgment

Prior to deploying a dynamic "No Turn On Red," consider whether the following characteristics exist: [1]

- Signalized locations with limited sign distance and/or unusual geometry
- Signalized locations where pedestrian activity occurs consistently.
- Signalized locations within school zones (especially at school crosswalks) and near libraries, senior centers, transit stations, or other pedestrian traffic generators.
- Signalized locations that intersect exclusive bicycle facilities (especially two-way bicycle facilities with contraflow bicycle traffic) and trail crossings.
- Any crosswalk where the MnMUTCD pedestrian volume and/or school crossing warrant is met (MnMUTCD (2011), Section 4C, Warrants 4 and 5).

Alternative Countermeasures (Other solutions)

Prior to installing a dynamic "No Turn on Red" sign, agencies should consider:

- A leading pedestrian interval

Maintenance Considerations

Recommend routine calibration and checking the clock and bulbs.

Other Considerations

It's important to provide education to explain reasoning for a turn restriction change.

Educate-Encourage-Enforce

RESOURCES/FOOTNOTES

1. Minnesota's Best Practices for Pedestrian and Bicycle Safety, MnDOT (2021) p. 35
2. NS 654 Dynamic No Right Turn on Red – Literature Search, MnDOT (2021)

APPENDIX A - TECHNOLOGY ENHANCED TRAFFIC CONTROL USAGE POLICY - CITY OF ELK RIVER

Technology Enhanced Traffic Control Policy

Technology Enhanced Traffic Control Policy

Purpose

The City of Elk River seeks to optimize its existing traffic control measures in locations where unique situations exist. With evolving Technology Enhanced Traffic Control devices, it is crucial to analyze the effectiveness of each device and determine whether their use factually increases the safety and well-being of the public.

This policy defines how devices are evaluated and recommended for application. Devices failing to meet the guidelines established by this policy will not be considered for installation unless they are a replacement to a previously installed, older technology system (standard flashing beacons, etc.).

Policy

Devices considered for use include: flashing LED regulatory (stop and yield) and warning (curve ahead, etc.) signs, digital speed feedback signs, and rectangular rapid-flashing beacons at pedestrian crosswalks. New devices, as developed, will be considered for addition to the policy.

The city will follow guidance for appropriate use as provided by the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD).

Flashing LED Signs (Regulatory and Warning)

Light Emitting Diode (LED) units may be used individually within the legend of a sign and/or the border of a sign to improve the conspicuity or to increase the legibility of sign legends and borders.

Prior to implementing a flashing LED sign, the following conspicuity improvement alternatives shall first be considered:

- Install an advanced warning sign on approach to the intersection or warning condition.
- Increase the size of the existing signage.
- Install a second sign of equal or lesser size on the left-hand side of the road (if allowed by MN MUTCD).
- Add one or more red or orange flags (cloth or retroreflective sheeting) above a standard sign, with flags oriented at 45 degrees to the vertical.
- Add a strip of retroreflective material to the sign support.

Flashing regulatory and warning signs shall only be considered for installation in situations necessitating enhanced visibility of the sign not accomplished by the above treatment techniques. The city will follow the MnDOT Traffic Engineering Manual to create premises for use. For local road situations the manual provides instruction that use of these devices should be limited to locations where both of the following conditions exist:

- Limited visibility on approach to an intersection or roadway condition requiring warning, as determined by the sight distance criteria for Warrant 1 in Section 9-4.02.012 in the Traffic Engineering Manual.
- A history of crashes documented to be caused by a failure to stop or adherence to warning, and deemed preventable by implementation of conspicuity improvements.

Speed Feedback Signs

These signs provide a real-time dynamic display of the driver's vehicular speed at the location where speeding and safety has been documented as a problem. When considering use of these signs, at least four (4) of the following conditions must be met:

- The 85^{th} percentile speed exceeds the posted speed limit by at least 5 MPH during the time period of concern.
- A speed transition area exists.
- The area of interest is within the vicinity of a school or other high pedestrian traffic area.
- The posted speed is 40 MPH or less.
- The road is under city jurisdiction.

Installation may be considered when three (3) of the above five (5) conditions are met, and crash data and documented repeat lane departures can clearly be linked to excessive speed in the area of interest.

Speed Feedback Signs shall also meet the following technical specifications when implemented:

- Installation must be used in conjunction with the traditional speed limit sign.
- When activated, the sign display shall give drivers immediate feedback on their individual driving speed.
- When traveling above the posted speed limit, the sign shall rapidly flash or have other dynamic elements.
- When installed in association with school speed zones, the Speed Feedback Signs shall operate only when the school speed zone is in effect.
- The installation shall not interfere with the visibility and general effectiveness of any other signs in the area.

Rectangular Rapid Flashing Beacons (RRFBs)

RRFBs are user-actuated LEDs that supplement warning signs to increase awareness of a pedestrian crossing location. They are activated by a push button which triggers the LEDs to display an irregular flash pattern which can help alert drivers of the approaching crosswalk.

Prior to implementing RRFBs, the following conspicuity improvement alternatives shall first be considered:

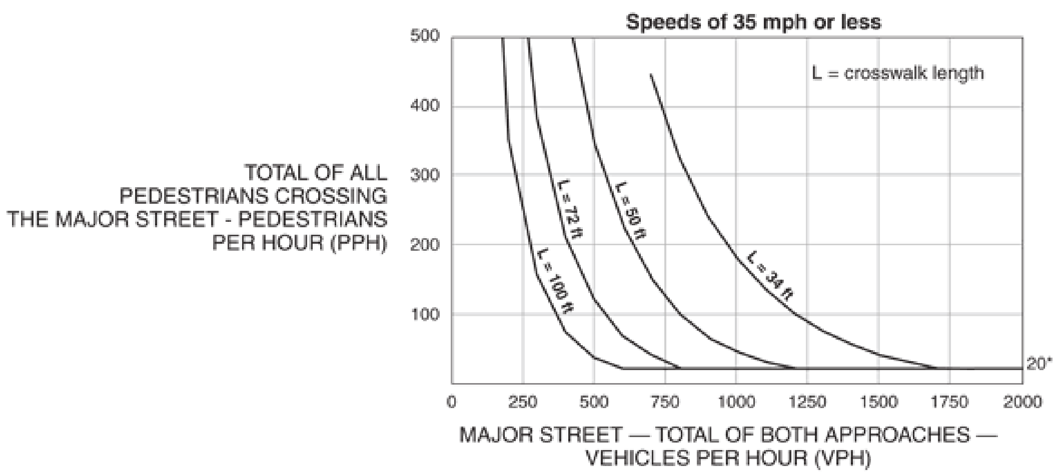
- Add crosswalk pavement markings.
- Install an advanced warning sign on approach to the crosswalk.
- Increase the size of the existing signage.
- Install a second sign of equal or lesser size on the left-hand side of the road (if allowed by MN MUTCD).

- Add one or more red or orange flags (cloth or retroreflective sheeting) above a standard sign, with flags oriented at 45 degrees to the vertical.
- Add a strip of retroreflective material to the sign support.
- Add an In-street Pedestrian Crossing sign.

RRFBs shall only be considered for installation in situations necessitating enhanced visibility of the crosswalk not accomplished by the above treatment techniques.

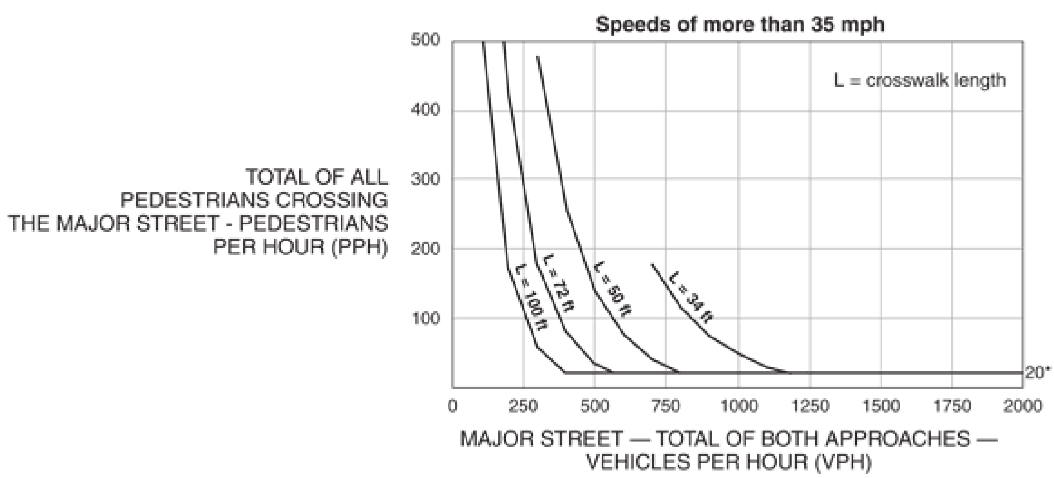
The analysis for determining if RRFBs shall be used is specified in figures 4F-1 and 4F-2 from Part 4 of the Manual on Uniform Traffic Control Devices as shown below. Variables that influence the proper procedure include the number of pedestrians crossing at a location, the volume and speed of crossing vehicular traffic and the length of the crosswalk.

Figure 4F-1. Guidelines for the Installation of Pedestrian Hybrid Beacons on Low-Speed Roadways



* Note: 20 pph applies as the lower threshold volume

Figure 4F-2. Guidelines for the Installation of Pedestrian Hybrid Beacons on High-Speed Roadways



* Note: 20 pph applies as the lower threshold volume

RRFBs shall be limited in use to crosswalk locations that exist at non-controlled intersections or other midblock locations where vehicular traffic would otherwise not be required to stop.

Costs

Annual budgets are prepared without including installation of any new Technology Enhanced Traffic Control devices due to the large and variable costs for each individual system.

Requests for Technology Enhanced Traffic Control devices, found to meet the guidelines established in this policy, shall be considered for inclusion in the following year's budget or Capital Improvement Plan.

Requests for installation within the current budget year found to meet the guidelines established by this policy may be considered if they are accompanied with a donation of all costs associated with the purchase, installation and maintenance of the system. Acceptance of the donation will be by the City Council and shall not obligate the city to future replacement costs.

Technology Enhanced Traffic Control Policy
Policy History

Adopted by:	On (date)	Item #

APPENDIX B - EFFECTIVE DEPLOYMENT OF RADAR SPEED SIGNS (LOCATION SPECIFIC GUIDANCE)

Effective Deployment of Radar Speed Signs

A Project Conducted Under California and Oregon Advanced Transportation Systems (COATS) Phase IV

Final Report

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U.S. Department of Transportation
Research and Innovative Technology Administration

December, 2010

DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the California Department of Transportation or Montana State University. This reference document does not constitute a standard, specification or regulation. It is not intended to replace existing Caltrans mandatory or advisory standards, nor the exercise of engineering judgment by licensed professionals. The document is simply a reference guide, which compiles information and concepts from various agencies and organizations faced with similar transportation issues. Caltrans acknowledges the existence of other practices and provides this document as a reference guide for those responsible for making professional engineering decisions.

Alternative accessible formats of this document will be provided upon request. Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation to participate, should contact Kate Heidkamp, Assistant Director for Communications and Information Systems, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT 59717-4250, telephone number 406-994-7018, e-mail: KateL@coe.montana.edu.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Radar speed signs have seen increased application in recent years in communities across the United States. These devices, which measure (by radar) and display the speed of vehicles passing by, are typically mobile (trailer-based) units or are permanent pole/post-mounted digital display boards. Smaller portable pole/post-mounted displays intended for brief deployments have also recently become available. Such devices are used to reduce traffic speeds by making drivers aware of how fast they are moving relative to the speed limit and inducing them to adjust their speed accordingly.

Typically, the deployment of radar speed signs has been conducted in an unscientific manner and has been driven by subjective judgment rather than engineering studies. In other words, devices are typically placed where there is a perceived problem with little quantification of the problem itself. For example, if speeding is perceived to be a problem by residents of a residential neighborhood, police may place a radar speed trailer in the area in response to resident complaints. While this serves to placate residents and likely will have some impact on reducing speeds in the short term, excessive use of signage in such cases, particularly for an extended period of time, could lead motorists to disregard the warning in the long term. Consequently, it is necessary to establish criteria regarding when/how such signage can be deployed and operated to address safety and speed issues effectively. In the context of this work, those criteria are referred to as warrants. Caltrans District 2 personnel have indicated that there is a need to develop warrants for the use of radar speed signage in their district. These warrants would also be considered applicable to other districts throughout California.

The objectives of this research were to establish what situations warrant radar speed signs, whether they have been effective in similar applications, where such signs should be located (both setting and placement), and what technical specifications should be adhered to when procuring, operating and maintaining them. These objectives were pursued through a review of research reports and documentation conducted nationally and internationally, as well as the engineering practices and policies employed in California and by other states and localities. Based on this review, as well as a review of maintenance practices and evaluation of the effectiveness of such signage in applications similar to those intended for use in California, warrants and specifications were developed to guide future applications of radar speed signs. Two levels of guidance were developed: general guidance and location-specific guidance.

General guidance warrants applied to cases where a radar speed sign may be used to address excessive mean speed and 85th percentile speed issues, ADT levels, speed limit compliance issues, accident history, pedestrian presence, and existing posted speed limits. Location-specific guidance applied to the use of radar speed signs in school and park zones, work zones, and general street locations such as transition zones, curve warning sign locations, and signal approaches. To a large extent, these warrants cover a wide range of the deployment settings already pursued in California. Where the warrants are likely to differ from current practice is in the call for different thresholds to be met before deploying signage. Employing the warrants developed in this work will lead to a more systematic approach to the use of radar speed signs and, potentially, greater acceptance of and compliance with posted speed limits by the driving public.

In addition to developing warrants for the use of radar speed trailers, specifications were developed for such equipment to guide practitioners in future purchases and deployments. The

specifications developed related to the physical and functional specifications for both permanent post-mounted radar speed signs (and portable post-mounted signs) as well as trailer-based radar speed signs. The specifications represent a minimum that should be employed by agencies when considering a radar speed sign purchase. They detail all aspects (electrical, dimensional, luminary, performance, etc.) of radar speed signs (and trailers for mobile units), providing purchasers who may not be familiar with such devices with specific parameters to meet in procurement. Applying these specifications would help in improving the uniformity and standardization of the equipment procured and deployments pursued by agencies.

1. INTRODUCTION

Radar speed signs[1] have seen increased application in recent years in communities across the United States. These devices, which measure (by radar) and display the speed of vehicles passing by, are typically mobile (trailer-based) units or are permanent pole/post-mounted digital display boards. Smaller portable pole/post-mounted displays intended for brief deployments have also recently become available. An example of each type of these units is presented in Figure 1-1. Such devices are used to reduce traffic speeds by making drivers aware of how fast they are moving relative to the speed limit and inducing them to adjust their speed accordingly.

Trailer unit (Veneziano)

Pole-mounted unit (Turnbull)

Temporary pole-mounted unit (Veneziano)

Figure 1-1**:** Radar speed signs

[1] For the purposes of this report the term radar speed signs will be used. Other names for such devices include mobile roadside speedometers, speed trailers, dynamic speed displays, speed displays, speed feedback signs, driver feedback signs, and speed monitoring displays. Regardless of the naming convention, each describes the same general device.

While these radar speed signs, particularly trailer-based and portable sign-mounted versions, can be deployed anywhere that excessive vehicle speeds are a concern, two primary applications have been documented in the literature: school zones and work zones. These are locations where excessive vehicle speeds are of significant safety concern. Consequently, much research has been performed on the effectiveness of radar speed signs in reducing vehicle speeds in these applications. This research and its results are discussed in detail in Chapter 2.

In addition to these uses, a common application of such signage in a rural context is the transition zone between high speed roadways and lower speed roads inside of towns. These high-to-low speed transition areas are prevalent throughout the California Oregon Advanced Transportation Systems (COATS) region of northern California and Southern Oregon and present local communities with a safety challenge. To address issues of speeding in such locations, many communities deploy radar speed signs to alert motorists to their current speed compared to the posted speed limit. In such applications, determining locations where such signage is warranted versus locations where it may not provide a significant impact is important.

Typically, the deployment of radar speed signs has been conducted in an unscientific manner and has been driven by subjective judgment rather than engineering studies. In other words, devices are typically placed where there is a perceived problem with little quantification of the problem itself. For example, if speeding is perceived to be a problem by residents of a residential neighborhood, police may place a radar speed trailer in the area in response to resident complaints. While this serves to placate residents and likely will have some impact on reducing speeds in the short term, excessive use of signage in such cases, particularly for an extended period of time, could lead motorists to disregard the warning in the long term. Consequently, it is necessary to establish criteria regarding when/how such signage can be deployed and operated to address safety and speed issues effectively. In the context of this work, those criteria are referred to as warrants. Caltrans District 2 personnel have indicated that there is a need to develop warrants for the use of radar speed signage in their district. These warrants would also be considered applicable to other districts throughout California.

1.1. Research Objective

Radar speed signs are typically deployed on a case-by-case basis and decisions regarding when and where to deploy them are often driven by motives other than sound engineering practice. This is due, at least in part, to the limited documentation that provides deployment guidance. However, a good amount of documentation does exist regarding the effectiveness of radar speed signs in various applications. This information can be employed in developing more specific guidance for practitioners regarding when radar speed signs may be warranted and what their expected impacts might be.

The objectives of this research are to establish what situations warrant radar speed signs, whether they have been effective in similar applications, where such signs should be located (both setting and placement), and what technical specifications should be adhered to when procuring, operating and maintaining them. These objectives were pursued through a review of research reports and documentation conducted nationally and internationally, as well as the engineering practices and policies employed in California and by other states and localities. Based on this review, as well as a review of maintenance practices and evaluation of the effectiveness of such signage in applications similar to those intended for use in California, warrants and specifications were developed to guide future applications of radar speed signs.

1.2. Approach

It is crucial that this document offer guidance that a practitioner[2] can refer to when deciding when and where to place such equipment. Therefore, the approach taken in completing this work will be to review and synthesize current practice within and outside of California related to radar speed signs. At present, the California Manual on Uniform Traffic Control Devices (MUTCD) contains standards, guidance, options and support related to these devices. As that document is already referred to by practitioners, it serves as the foundation for the guidance that is presented in this document.

1.3. Report Outline

This report contains seven chapters. Chapter 1 provides an introduction and background on radar speed signs and the research problem being investigated. Chapter 2 reviews research that has been conducted on radar speed signs, while Chapter 3 reviews the practices and guidance employed in California, nationally and in other states regarding radar speed signs. Chapter 4 presents the results of a survey of California practitioners who have experience with radar speed signs. Chapter 5 presents the warrants developed for the use of radar speed signs, while Chapter 6 presents specifications to consider when purchasing such devices. Chapter 7 presents the conclusions and recommendations drawn from this research, as well as ideas for future work.

Six appendices are provided that present additional information related to research, specific state guidance, responses from the survey, an overview on how to conduct a spot speed study, sign specifications employed by one California community, and the sign specifications developed by this project in a tabular format.

[2] As radar speed signs are considered a traffic control device, their application should be performed by professional engineers who have received training in transportation engineering.

2. LITERATURE REVIEW

Studies regarding the effectiveness of radar speed signage in reducing speeds and/or crashes for a specific application are beyond the scope of this work. Therefore, one of the approaches taken in developing warrants for radar speed signs was to consult the findings of past research. To accomplish this, a review of available literature was undertaken. The work presented in this chapter synthesizes the results of studies for use in developing guidance/criteria for consultation and application in California. To a significant extent, previous research studies have examined the impacts of various applications on speeds. Unfortunately, as the following review indicates, studies related to safety (i.e., crash reductions) are essentially non-existent. Summary tables providing additional details related to each of the studies discussed in the following sections are presented in Appendix A.

2.1. Speed Impacts

Pesti and McCoy examined the impacts on speed that radar speed trailers had in a rural interstate work zone in Nebraska (1). The researchers evaluated the effectiveness of speed trailers in a 2.7-mile work zone on I-80 near Lincoln over a five-week period. Results indicated that the presence of trailers reduced mean speeds by 3 to 4 miles per hour (mph), reduced 85th percentile speeds from 2 to 7 mph, and increased vehicle compliance with speed limits between 20 and 40.

Casey and Lund examined the impacts of speed trailers on two- and four-lane urban roadways in Santa Barbara, California (2). Study locations included school zones as well as residential, commercial and undeveloped areas. Results in school zones indicated reductions in mean speeds between 1.5 and 5 mph. Results for other study locations showed mean speed reductions of 10 percent alongside the radar trailers and 7 percent downstream.

Bloch examined the effectiveness of radar speed trailers with the presence of enforcement (3). The study location was Riverside, California, along two-lane, residential roads. Results indicated that at the location of the trailer, under both enforcement and non-enforcement conditions, a speed reduction of 6.1 mph was observed. Downstream of the trailer, reductions of 2.9 mph (without enforcement) and 5.9 mph (with enforcement) were observed during deployment. One week after removal of the trailer, speed reductions of 0.6 mph (at the former trailer location) and 1.7 mph (downstream) were observed for deployments that did not coincide with enforcement. Where enforcement had been used in conjunction with the speed trailer, one-week reductions were 0.6 mph both at the trailer location and downstream.

In work cited by Bloch (3), an examination of deployments in Orange County, California, focused on six roads, including arterials, residential collectors and local roads (4). Results indicated statistically significant reductions in 85th percentile speeds, as well as an average speed reduction of 4 mph at all sites.

Garber and Srinivasan examined the effectiveness of fixed overhead Changeable Message Sign (CMS) systems programmed to display “You Are Speeding Slow Down” when a speeding vehicle was detected by radar (5). The researchers found that the CMS with radar was effective in reducing the speeds of speeding drivers in a work zone for short deployment durations and remained an effective speed control technique when used for prolonged periods (deployments up to seven weeks). In addition, the researchers found that speed variances tended to be reduced.

Lee et al. examined the effectiveness of speed monitoring displays (a fixed sign deployment) in reducing school zone speeds in South Korea (6). Speeds were collected before deployment, and again two weeks and 12 months after deployment. Prior to the display installation, 26.5 percent of motorists were observed to be exceeding the 50 km/h (30 mph) speed limit, while only 9.9 percent were speeding two weeks after deployment, and 5.5 percent 12 months after deployment. Additionally, 85th percentile speeds fell from 33 mph before deployment to 28 mph (two weeks) and 27 mph (12 months) afterward. Kolmogorov-Smirnov two-sample tests were performed to determine whether the before-and-after speed distributions were similar, with results indicating that a significant change in speed distributions had occurred.

McCoy et al. examined the effectiveness of speed monitoring displays in reducing speeds in a South Dakota interstate work zone (7). It was found that mean vehicle speeds were reduced by these deployments by 4 to 5 mph, while the percentage of vehicles speeding—originally 74 percent—fell by 20 to 25 percent.

Carlson et al. evaluated the use of speed trailers at high-speed temporary work zones in rural areas (8). Speed trailers were found to reduce mean speeds at the trailer site by 2 to 3 mph, and within the work zone itself by 4.5 to 5.7 mph (cars) and 2.8 to 4.4 mph (trucks). Additionally, the trailers had an impact on the percentages of speeders within the work zone. For cars, reductions from 9.6 to 2.0 percent (site 1) and 7.9 to 2.4 percent (site 2) were observed. The percentage of speeding trucks was reduced from 32.0 to 7.6 percent and 17.0 to 7.4 percent at sites 1 and 2, respectively.

Garber and Patel examined the impact of CMS's combined with radar on vehicle speeds in temporary work zones (9). Signs were set up at the beginning, midpoint and end of each work zone. Rather than showing the speed of the vehicle, the displays presented messages such as "Excessive Speed, Slow Down" when speeding vehicles were detected. The research found that at all seven work zone sites examined, mean speeds fell by 4 to 7 mph between the first and second sign, and from 1 to 3 mph between the second and third sign. Similarly, 85th percentile speeds fell by 6 to 11 mph between the first and second sign, and from 2 to 3 mph between the second and third sign. In addition, both mean and 85th percentile speeds fell below the posted work zone speed limits at the second sign location (midpoint of the work zone). All message texts employed showed similar declining trends in vehicle speeds.

Ullman and Rose evaluated dynamic speed displays on static signage in a variety of applications, including their use in school zones, in the transition area before school zones, on the approaches to signalized intersections, and on sharp horizontal curves (10). Results indicated that mean speeds at the school zone site fell by 9 mph both short term (one week) and long term (four months) following deployment. Mean speeds at the school zone transition sites fell by 2 to 3 mph short term and 1 mph long term, while speeds at the signalized intersection approach sites fell by 3 mph short term and 0 to 4 mph long term. Finally, the sharp horizontal curve sites experienced mean speed reductions of 2 to 3 mph short term and 0 to 2 mph long term. Similar to these trends, 85th percentile speeds also were reduced 10 mph short term and 8 mph long term in school zones, 3 to 4 mph short term and 2 mph long term at school zone transitions, 3 to 4 mph short term and 0 to 3 mph long term at signalized intersection approaches and 2 to 3 mph short term and 0 to 3 mph long term at horizontal curve sites. Overall, the authors concluded that the reduction achieved by the signage were more dramatic within school zones, with the remaining application areas exhibiting less pronounced impacts.

Teng et al. evaluated speed monitoring displays (speed trailers) for interstate and principal arterial work zones in Las Vegas, Nevada (11). This evaluation included an examination of different enhancements, including message sizes, the use of flashing messages/speeds, and the presence of multiple trailers in the work zone. The research found that, overall, the speed trailers reduced mean speeds by 8 to 9 mph. In addition, it was found that the size of the sign and whether the message was presented in a flashing display showed a significant impact on speeding likelihood and speed reduction in work zone applications.

Work by Wertjes in South Dakota evaluated the effectiveness of speed monitoring displays in reducing speeds in interstate work zones (12). CMS with LIDAR (Light Detection and Ranging) speed measurement were used to warn motorists that they were speeding and needed to slow down in advance of the work zone taper, at the beginning of the taper, and at its end. Results indicated that mean speeds changed slightly following the deployment of CMS signage, falling by 1.7 mph in advance of the taper, 1.6 mph at the beginning of the tape, and remaining unchanged at the end of the taper. Similarly, 85^{th} percentile speeds fell by 2.1 mph in advance of the taper, 3.9 mph at the beginning of the taper, and 1.2 mph at the end of the taper. An ANOVA (analysis of variance) on these changes in speeds indicated that mean speed differences were not significantly changed, while 85^{th} percentile speeds changed significantly. This indicated that higher speed motorists (i.e., the target of the signage) were being influenced by the displays.

Wang et al. evaluated different speed reduction strategies for work zones in Georgia, including a CMS with radar detection (13). The research found that significant speed reductions of 7 to 8 mph were achieved in the vicinity of the sign immediately following deployment. Additionally, the authors noted that speed variance also decreased significantly following deployment. Longer term speed reductions of between 1 and 3 mph were also observed. Neither short-term nor long-term speed reductions appeared to extend a great distance into the work zone.

Sorrell et al. examined the reduction in vehicle speeds in South Carolina work zones where CMS with radar deployments were made (14). Signage was deployed in an interstate work zone and in three two-lane highway work zones. Results indicated that the use of such signage produced reductions in mean speeds of 7 to 9 mph in the interstate work zone and 5 to 7 mph in the two-lane highway work zones. Similarly, 85^{th} percentile speeds were reduced by 6 to 9 mph in the interstate work zone and 2 to 4 mph in the two-lane highway work zones.

Work in Texas by Fontaine et al. examined the impacts of speed display trailers in rural work zones (15). Results indicated that average vehicle speeds were reduced by 5 mph. Additionally, the number of vehicles observed to be traveling in excess of the speed limit was decreased.

The Maine Department of Transportation evaluated radar-activated speed warning signs in two school zones (16). It was found that mean speeds were reduced by 2 to 4 mph following deployment of the signage. Additionally, the percentage of vehicles exceeding the speed limit at the two sites fell by 4 percent and 20 percent. Despite these reductions, more than 70 percent of vehicles still were observed to be exceeding the speed limit at each site.

In work conducted for three Minnesota counties, Sandburg et al. examined the long-term effectiveness of dynamic speed monitoring displays for speed limit transitions (rural to urban) at four locations (17). Speeds were measured one week, two months, seven months and one year following deployment. Results indicated that mean speeds following deployment were reduced by 6 to 7 mph after 1 week, 3 to 8 mph after two months, 3 to 7 mph after seven months, and 6 to 8 mph after one year, depending on the site. Similarly, 85^{th} percentile speeds following deployment were reduced by 6 to 8 mph after one week, 5 to 11 mph after two months, 5 to 7 mph after seven months, and 5 to 9 mph after one year, depending on the site.

Maze examined the use of a speed monitor display in advance of work zone tapers on an interstate in Iowa (18). When placed 500 feet in advance of the work zone, moderate decreases in mean and 85^{th} percentile speeds were observed. These decreases were 3 mph for mean speeds and 5 mph for 85^{th} percentile speeds. Overall, these changes in speeds were not found to be statistically significant.

Saito and Bowie examined the use of speed monitoring displays (speed trailers) in increasing speed limit compliance for interstate work zones in Utah (19). Results indicated that mean speeds fell by 7 mph following deployment of the signage. However, the researchers noted that the deployment tended to lose its effectiveness after one week.

Saito and Ash evaluated a number of traffic safety initiatives in Utah to increase speed limit compliance in school zones (20). Among the practices examined was the use of speed monitoring displays, which were deployed in four urban/suburban school zones. Speeds were examined both short term following deployment (within the first month) and three months after deployment. Short-term mean speeds were found to be reduced by 1 to 3 mph, depending on the site, while 85^{th} percentile speeds fell by 2 to 4 mph. Changes to mean and 85^{th} percentile speeds were found to remain generally unchanged when collected three months after deployment.

Donnell and Cruzado examined the effectiveness of speed trailers in reducing speeds on rural Pennsylvania highways (21). The sites where speed trailers were deployed were primarily transition zones on two-lane highways. Results from data collected one week into the deployments indicated that mean speed reductions of 4.6 to 7.9 mph were achieved (not statistically significant). Additionally, speeds measured past the signage exhibited similar reductions, indicating that the influence of the sign remained constant for a distance. However, when speeds were measured one week following the removal of each deployment, results indicated that mean speeds increased by approximately 3.1 to 9.2 mph (statistically significant).

Chitturi and Benekohal evaluated the effectiveness of a speed feedback device on speeds in an interstate work zone in Illinois (22). Speed data were examined immediately as well as three weeks after deployment. Results indicated that speeds immediately following deployment fell by 4.4 mph, while three weeks after deployment speeds had fallen by 6.7 mph.

In a study for the Washington, D.C., District Department of Transportation, the effectiveness of driver feedback signs was examined (23). In general, mean speeds were observed to decrease by 1 to 7 mph, although at some sites slight increases were observed (generally 1 to 2 mph).

The City of Garden Grove, California, examined the impacts on 85^{th} percentile speeds that radar speed feedback signs had in school zones (24). Results indicated that 85^{th} percentile speeds were reduced by 1.5 to 9.8 mph, depending on the site.

Hallmark et al. examined various traffic-calming treatments for major routes in small communities in Iowa (25). Among the treatments examined were driver feedback signs and their impacts on reducing vehicle speeds in transition zones and one school zone. For transition zones, mean speeds one month following deployment fell by 1 mph, 0 mph after three months, 1 to 5.2 mph after nine months, and 1 to 3.4 mph after one year. Similarly, 85^{th} percentile speeds fell by 2 mph, 1 mph after three months, 1 to 4 mph after nine months, and 2 to 3 mph after one year. In the school zone application, speeds were only collected after three months due to a number of equipment difficulties. Results indicated that at this site, mean speeds after three months had fallen by 5.4 mph, while 85th percentile speeds had fallen by 7 mph.

Chang et al. investigated the effectiveness of "real-time driver feedback technology" on traffic speeds along collector and arterial roadways in King County, Washington (26). Speed data were collected before and after deployment of post-mounted signage that displayed driver speeds at four sites. Results indicated that mean speeds decreased between 1.19 and 2.21 mph at three of the four sites, with only one of these three sites producing a statistically significant reduction. The fourth site showed a statistically significant increase in speeds, albeit only 0.51 mph.

Tribbett et al. evaluated the use of dynamic curve warning systems in the Sacramento River Canyon of California (27). The system employed CMS and a radar unit to display both the advisory speed and a vehicle's operating speed in text and diagrammatic formats. In general, speed reductions for cars and trucks were between 1 and 5 mph, with reductions being statistically significant at several sites. Mean vehicle speed increased at two sites, although this was attributed to an increase in posted speed limits in the vicinity of and on the curve itself.

2.2. Safety Impacts

A review of literature found no published research findings on the safety impacts of radar speed signage. This is not surprising as the primary intention of radar speed signage is to slow motorists down. Safety improvements derived from such signage are primarily ancillary and likely to be minor. In reality, the temporary nature of many applications (e.g., radar speed trailers and CMS in work zones) limits the period during which crash reductions may occur. As a result, only permanent radar speed sign installations in school zones, residential areas and the like offer any potential to observe crash trends over time.

Only one study was identified that examined any relationship between radar speed signage and crashes. Work by the California Highway Patrol found that speed trailers produced a 9.8 percent reduction in crashes. However, this study was flawed in that it did not use comparison sites or controls for long-term crash trends (28).

2.3. Existing Warrants

A final research project, completed by the Enterprise Program[3], developed warrants for Dynamic Speed Display Signs (DSDS) for application to transition zones, posted speed adherence and intelligent work zones (29). The warrants are presented on a website, with the user presented with a series of questions to answer. Based on the user's response to each question, the website informs them whether or not a sign is warranted. The website and approach it presents are still considered to be in a research state, and it is stressed that "Visitors to the website shall not use the warrants for any purpose other than assisting this research effort and contributing to the project. The warrants have not yet been validated and therefore should not be used to make any formal assessments about the validity of, or need for technology devices (29)."

[3] The Enterprise Program is a pooled-fund comprised of Arizona, Iowa, Kansas, Michigan, Minnesota, Virginia, Washington, the FHWA, Ontario, Transport Canada and the Netherlands. It develops, evaluates and deploys Intelligent Transportation Systems for its member agencies and broader use.

The warrants developed ask a series of questions related to the application type of interest. These questions included:

Does the 85th percentile speed (as determined by a speed study) exceed the posted speed limit by at least 5 mph, or by at least 3 mph in a school zone? (Transition Zone and Posted Speed Adherence Warrants)
Does the zone experience a posted speed limit reduction of at least 10 mph? (Transition Zone Warrant)
Is the area within 500 yards of a major pedestrian generator (e.g. school, park, library, senior center, office building)? (Posted Speed Adherence warrant)
Is the area primarily a residential area or a heavily traveled pedestrian area? (Posted Speed Adherence warrant)
Is the posted speed limit 35 mph or less? (Posted Speed Adherence warrant)
Is the work zone currently in operation and observations suggest that the 85% speed at a location within the work zone exceed the posted speed limit by at least 5 mph? (Intelligent Work Zone Warrant)
Will workers be located adjacent to the open traffic lane? (Intelligent Work Zone Warrant)
Are there hazardous roadway conditions, such as a temporary unusually tight curve, or a rough road surface, requiring extra driving precaution? (Intelligent Work Zone Warrant)
Are there other Dynamic Speed Display Signs along the route encountering the speed transition, within 5 miles in either direction (excluding DSDS within school zones)? (29)

Depending on application selected, more than one of these criteria need to be met before a sign is justified. One aspect of the warrants worth noting is the inclusion of criteria regarding the distance between radar speed signs (5 miles). While the basis for this distance is not provided, it is of interest in that it addresses the concern for the potential overapplication of radar speed signs along a route or in proximity to one another.

While the warrants posted on the Enterprise Program website appear agree with many of the research results and discussions provided in the previous sections, no documentation is provided to explain how they were developed. Of course, as the work presented on the website is cited as being research and not yet validated, this is not surprising. It can be assumed that the warrants were developed based on a review of literature, engineering experience, or a combination of the two. However, in the absence of documentation regarding their development, and given that they are still considered research in nature, these warrants should be considered as simply a data point for consideration when developing the warrants discussed in later chapters of this document.

2.4. Summary

This chapter has provided an overview and summary of research on radar speed sign deployments. Results of this review indicated that radar speed signs were used in a number of common applications, including work zones, school zones, residential and commercial areas, and speed transition zones (signal approaches, rural to urban transitions, curve approaches, etc.). The problems that radar speed signs were typically employed to address included excessive mean and 85^{th} percentile speeds, safety concerns, traffic issues, posted speed compliance, pedestrian presence, and safety/speeding concerns in school zones, work zones, residential neighborhoods and commercial areas.

In general, the applications reviewed provided evidence that radar speed signs often achieved their specific objective, which was typically a reduction in speeds. Depending on the specific application and problem being addressed, changes in speeds ranged from small to significantly large. The long-term impact of such signage varied; in some cases it was reported to have a positive impact over many months, while in other cases radar speed signs were reported to lose effectiveness within weeks of their deployment. No rigorous statistical or even basic evaluations have examined the impacts of radar speed signs on reducing speed-related crashes. In only one instance have warrants for the use of radar speed signs been developed. These are still in an experimental stage and lack documentation regarding how they were developed. As a result, they cannot be considered substantial guidance which can be applied to meeting Caltrans' needs.

3. SYNTHESIS OF PRACTICE

This chapter provides an overview of national practices regarding radar speed signs from a legal standpoint and from a guidance document (MUTCD) standpoint. Additional information specific to California is provided for reader reference, as this work pertains to signage employed in that state. Finally, an overview of radar speed sign guidance and information from other states is presented.

3.1. National Practice

3.1.1. Legal Basis

To better understand the legal aspects of speed limit and signage practices nationally, a review of state legal codes and statues was performed. This review was conducted through an online search of legal information provided by state websites, as well as other resources such as Michies Legal Resources (http://www.michie.com/) and LexisNexis (http://www.lexisnexis.com/). All of these sources provided search engines that allowed for text searches to be made for information and laws related to speed limits, traffic control devices/manuals, and radar speed feedback signs. These resources allowed for a comprehensive review of state law, including information related to the establishment of speed limits, the requirements for signing said speed limits, and current laws addressing the topic of radar speed signage. Note that every attempt was made by the authors to review all pertinent information regarding the legal aspects identified. However, as the authors are not legal professionals and the project budget precluded an exhaustive legal review, it is possible that relevant laws and/or details may have been missed.

The overview of legal codes and statutes found that all states establish speed limits for state-controlled routes, with the option of raising or lowering those speed limits granted to state and local transportation agencies (i.e., DOTs or their equivalent). All laws reviewed required such changes be based on engineering studies of speeds. Similarly, local authorities were granted the power to develop and modify speed limits on non-state routes. The power to enforce speed limits is granted to the respective law enforcement agencies, as would be expected. The information reviewed strictly pertained to the establishment of speed limits; in no instance did it discuss issues related to signage.

The majority of state laws specify the adoption of some form of manual pertaining to the use of traffic control devices such as signage. Typically, this language reads as follows: the transportation director/commission shall adopt a manual and specifications of uniform standards for traffic control devices consistent with the provisions of the vehicle code for use upon highways. In some instances, laws said that the manual should conform to the Manual on Traffic Control Devices as adopted by the American Association of State Highway Officials. In other instances, the laws specifically stated that the state adopt a manual derived from the MUTCD (i.e., a state supplement). Regardless of the form the laws take, the documents they promote may or may not provide guidance relating to radar speed signs. In the case of states that develop supplemental information to the MUTCD, radar speed signage may or may not be discussed. This is the result of state’s adding or deleting specific information provided by the Federal MUTCD for their own state supplemental edition, depending on their preference. The specifics in such cases are provided in greater detail in the next section. In cases where a state chooses to adopt the Federal MUTCD with no changes, radar speed signage is specifically covered in three sections: 2B.13, 2B.18 and 6F.55.

The legal review also looked more specifically at radar speed signage. A search was made of statutes from each state to determine whether specific laws pertaining to such signage had been adopted. This search involved a number of different terms (see footnote 1 in Chapter 1) in an attempt to uncover all relevant laws that dealt with radar speed signage. Only Pennsylvania was found to have implemented a specific law pertaining to "Speed Display Signs." Specifically, that law reads:

§ 212.8. Use, test, approval and sale of traffic-control devices.

(a) Statutory requirements. Under 75 Pa.C.S. §6127 (relating to dealing in nonconforming traffic-control devices), it is unlawful for a person to manufacture, sell, offer for sale or lease for use on the highway, any traffic-control device unless it has been approved and is in accordance with this title.

…(6) Work zone traffic-control devices, including the following:

...b) Devices requiring Department approval. Department approval is required prior to the sale or use of the following types of traffic-control devices on any highway:

…(ix) Speed display signs, as used to inform motorists of the speed of their vehicles.

As the reader should note, this information pertains to such devices in highway work zones. Additionally, this law only pertains to the approval of such signage by the Pennsylvania Department of Transportation, presumably for use on state highway projects. This was the only legal information identified specifically related to radar speed signage by any state.

The conclusion to be drawn from the absence of specific legal instruction related to radar speed signs is that their use is at the discretion of the relevant authorities. Their use likely does not require a legal basis for two reasons. First, these devices do not explicitly change the prevailing speed limit; rather, they simply indicate the speed limit in effect at the site by providing supplemental signage. Secondly, such signage does not constitute enforcement. While it may be used in conjunction with enforcement activities, the sign itself is only displaying the motorist's current speed and does not perform any enforcement task, unlike devices such as photo-radar units that are used in the enforcement of traffic laws.

3.1.2. Federal Guidance

In general, a number of states default to the use of the version of the MUTCD published by the Federal Highway Administration. Guidance specific to radar speed signs is provided in sections 2B.13, 2B.18 and 6F.55.

Section 2B.13 (Speed Limit Sign) of the MUTCD states "A changeable message sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit sign" (30). Section 2B.18 of the MUTCD addresses the location of speed limit signs. Although this section does not discuss radar speed signs in detail, it does provide a standard relative to where such signs should be placed. Specifically, the text indicates that the placement of radar speed signs should follow the convention set forth for ordinary static signage. In other words, radar speed signs (either post mounted or mobile) should be placed where speed changes occur (e.g., school zones, municipal boundaries, etc.). This would indicate that such devices should be placed where other, existing speed limit signage is present rather than in a random location. Finally, Section 6F55 provides standards and guidance related to portable CMS, which includes trailer-based radar speed signs. Text from these sections are included below:

Section 2B.13

Guidance: If a changeable message sign displaying approach speeds is installed, the legend YOUR SPEED XX km/h (MPH) or such similar legend should be shown. The color of the changeable message legend should be a yellow legend on a black background or the reverse of these colors (30).

Support: Advisory Speed signs are discussed in Sections 2C.36[4] and 2C.46[4] and Temporary Traffic Control Zone Speed signs are discussed in Part 6 (30).

Section 2B.18

Standard: Speed Limit (R2-1) signs, indicating speed limits for which posting is required by law, shall be located at the points of change from one speed limit to another. At the end of the section to which a speed limit applies, a Speed Limit sign showing the next speed limit shall be installed. Additional Speed Limit signs shall be installed beyond major intersections and at other locations where it is necessary to remind road users of the speed limit that is applicable. Speed Limit signs indicating the statutory speed limits shall be installed at entrances to the State and at jurisdictional boundaries of metropolitan areas (30).

Section 6F.55

Standard: Portable Changeable Message signs shall automatically adjust their brightness under varying light conditions, to maintain legibility. The control system shall include a display screen upon which messages can be reviewed before being displayed on the message sign. The control system shall be capable of maintaining memory when power is unavailable. Portable Changeable Message signs shall be equipped with a power source and a battery back-up to provide continuous operation when failure of the primary power source occurs. The mounting of Portable Changeable Message signs on a trailer, a large truck, or a service patrol truck shall be such that the bottom of the message sign panel shall be a minimum of 2.1 m (7 ft) above the roadway in urban areas and 1.5 m (5 ft) above the roadway in rural areas when it is in the operating mode. The text of the messages shall not scroll or travel horizontally or vertically across the face of the sign (30).

Guidance: "Portable Changeable Message signs should be used as a supplement to and not as a substitute for conventional signs and pavement markings… The Portable Changeable Message signs should be sited and aligned to provide maximum legibility… Portable Changeable Message signs should be placed on the shoulder of the roadway or, if practical, further from the traveled lane. They should be delineated with retroreflective TTC devices. When Portable Changeable Message signs are not being used, they should be removed; if not removed, they should be shielded; or if the previous two options are not feasible, they should be delineated with retroreflective TTC devices. Portable Changeable Message sign trailers should be delineated on a

[4] Each of these sections discusses the location of traditional static speed limit signage.

permanent basis by affixing retroreflective material, known as conspicuity material, in a continuous line on the face of the trailer as seen by oncoming road users" (30).

3.2. California Guidance

While no California state laws regulate the use of radar speed signs, state code does establish the basis for implementation of the California MUTCD. This language can be found in Section 21400:

The Department of Transportation shall, after consultation with local agencies and public hearings, adopt rules and regulations prescribing uniform standards and specifications for all official traffic control devices placed pursuant to this code, including, but not limited to, stop signs, yield right-of-way signs, speed restriction signs, railroad warning approach signs, street name signs, lines and markings on the roadway, and stock crossing signs placed pursuant to Section 21364.

The Department of Transportation shall, after notice and public hearing, determine and publicize the specifications for uniform types of warning signs, lights, and devices to be placed upon a highway by any person engaged in performing work which interferes with or endangers the safe movement of traffic upon that highway. Only those signs, lights, and devices as are provided for in this section shall be placed upon a highway to warn traffic of work which is being performed on the highway. Any control devices or markings installed upon traffic barriers on or after January 1, 1984, shall conform to the uniform standards and specifications required by this section.

In light of this instruction, it is clear that the authority for the establishment of sign usage rests in the hands of the Department of Transportation (Caltrans). Uniform specifications should be created to govern signage and other traffic control devices. While not explicitly stated, the development of such guidance can be assumed to stem from that provided by the MUTCD. Consequently, Caltrans has amended the MUTCD guidance to meet the needs of the state.

Rather than referencing radar speed signs as the MUTCD does (as changeable message signs), the California MUTCD refers to the devices as Vehicle Speed Feedback Signs. Aside from this, little difference exists between the guidance provided by the MUTCD and the California MUTCD. Indeed, the portion of the text that discusses radar speed signs is identical to that of the MUTCD, stating[5] "A *Vehicle Speed Feedback* sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit *(R2-1)* sign" (31). The entire section relevant to radar speed signs provided by the California MUTCD reads as follows:

Vehicle Speed Feedback Signs
Option:

- A Vehicle Speed Feedback sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit (R2-1) sign.

Standard (**bolded** by Caltrans):

- **If a Vehicle Speed Feedback sign displaying approach speeds is installed, the legend shall be YOUR SPEED XX.**

[5] I*talics* indicate differences between the two texts

- **The numerals displaying the speed shall be white, yellow, yellow-green or amber color on black background.**
- **When activated, lights shall be steady-burn conforming to the provisions of CVC Sections 21466 and 21466.5.**
- **Vehicle Speed Feedback signs shall not alternatively be operated as variable speed limit signs.**

Guidance:

- To the degree practical, numerals for displaying approach speeds should be similar font and size as numerals on the corresponding Speed Limit (R2-1) sign.

Option:

When used, the Vehicle Speed Feedback sign may be mounted on either a separate support or on the same support as the Speed Limit (R2-1) sign.

- In lieu of lights, legend may be retroreflective film for flip-disk systems.
- The legend YOUR SPEED may be white on black plaque located above the changeable speed display.

Support:

- Driver comprehension may improve when the Vehicle Speed Feedback Sign is mounted on the same support below the Speed Limit (R2-1) sign.

Vehicle Speed Feedback Signs are appropriate for use with advisory speed signs and with temporary signs in temporary traffic control zones.

The information provided by the California MUTCD establishes the foundation on which further warrants and specifications will be based. The California MUTCD indicates radar speed signs may be appropriate for use in conjunction with ordinary speed limit signs, advisory speed signs or as temporary signs in traffic control zones. Interestingly, no mention of the use of such devices in school zones is made in the text, although such use could be considered implied in conjunction with speed limit signs. Additionally, the reader is instructed to reference Part 6, Section 6C.01 for general information on static speed limit signs in school areas.

3.3. State Guidance

In addition to the Federal MUTCD, many states, as instructed by state law, may develop a supplemental MUTCD based on the Federal document. This guidance may or may not contain the guidance provided by the Federal document in sections 2B.13, 2B.18 and 6F.55, depending on what text the agency wishes to include or exclude. Finally, in addition to the guidance that may or may not be provided by the Federal or state-specific MUTCDs, additional guidance may be provided by an agency in the form of engineering memoranda, policy manuals, etc. In the course of reviewing state transportation agency information discussing radar speed signs, a total of 16 states (excluding California, discussed in the previous section) were found to provide specific guidance related to such devices. The following sections briefly discuss the guidance provided in these states, with more comprehensive information provided in Appendix B.

3.3.1. Arizona

The Arizona DOT provides information related to radar speed signs in its addendum to the MUTCD (32). Specifically, this information pertains to the use of such signage in school zones. Aside from this information, no additional guidance is provided. However, the reference to sections of the Federal MUTCD indicates that radar speed signs are also used in other locations, such as work zones, residential areas, etc., throughout the state.

3.3.2. Texas

Texas provides high level information regarding radar speed signs in the "Texas Manual on Uniform Traffic Control Devices" (33). Information provided in Section 2B.13, related to speed limit signing, provides an option and guidance for radar speed signage. The information applies to all potential applications of radar speed signage, regardless of their location or intended use.

3.3.3. Minnesota

The Minnesota DOT utilizes a technical memorandum to provide guidance on radar speed signs in the state (34). The text indicates that permission must be granted by MnDOT for the installation of radar speed signage, but it is not clear whether this pertains only to state-controlled routes. The text indicates that such signage may be employed in school and work zones. If one assumes that the discussion presented only applies to state-controlled route applications, then it is reasonable to conclude that other applications off the state system are permissible.

3.3.4. Missouri

The Missouri DOT presents information related to radar speed signs in its Engineering Policy Guide sections discussing CMS (35). The information presented applies to work zone applications; however, the text does discuss the opportunity for other applications using non-CMS equipment (e.g., mobile trailers, post-mounted signage, etc.).

3.3.5. Tennessee

The Tennessee DOT provides guidance related to radar speed signs in its Work Zone Safety and Mobility Manual (36). The information is specific to work zones, and no conclusions can be drawn with respect to the applications of radar speed signs in non-work-zone applications.

3.3.6. Kentucky

The Kentucky Transportation Cabinet provides general information on its use of radar speed signs through its driver safety manual (37). While the document does not provide guidance pertaining to the placement or standards of these devices, it does note their applications. Cited applications include high-crash corridors, work zones and other problem roadways, as well as in highway safety school programs, parades, festivals, and fairs.

3.3.7. Indiana

The Indiana DOT provides information specific to the use of radar speed signs in its MUTCD sections 2B.13 and 7B.11 (38). The text applies to general applications as well as school zones. While the information from Section 2B.13 does not specifically state the locations where radar speed signs may be employed, it is reasonable to assume they are permissible in typical applications, including school zones as cited in Section 7B.11, as well as work zones and other areas.

3.3.8. Michigan

The Michigan edition of the MUTCD specifically discusses the use of radar speed signs in Chapter 2 (39). The information provided by Michigan is similar to that of other states. In examining the information, it is evident that Michigan intends such devices to be employed in a variety of applications, including work and school zones.

3.3.9. Ohio

The Ohio DOT discusses radar speed signs in its MUTCD under speed limit information (40). The information provided is somewhat basic, but matches that presented by other states under similar sections of their respective MUTCDs.

3.3.10. Maryland

The Maryland State Highway Commission provides deployment guidelines for the use of radar speed signs in work zones in its document entitled "Use of Speed Display Trailers in Work Zones" (41). This document provides guidance related to equipment, locations, deployment duration, visibility, and so forth. The information represents a significant level of guidance regarding work zone applications of radar speed signs. However, the discussion of other applications for this signage is not cited in any corollary documents such as the state MUTCD.

3.3.11. Pennsylvania

The state of Pennsylvania specifically addresses radar speed signs in its state code. Information specific to these signs is provided in the document "Official Traffic Control Devices," Pennsylvania's supplement to the MUTCD (42). This information explicitly indicates projects over a specific funding threshold ($300,000) need to incorporate radar speed signage. Interestingly, most projects, including many small-scale ones, exceed this limit, necessitating the widespread use of such features throughout the state on state-funded projects.

3.3.12. Delaware

As supplemental information to the Delaware MUTCD, the state safety programs engineer developed a guidance memorandum discussing the use of radar speed signs (43). The information provided is perhaps the most specific in terms of addressing multiple sign types (trailer, post-mounted, etc.) of any state. This guidance applies to applications made on state-controlled roadways; however it is reasonable to assume that such guidance is also employed at the local level for applications made to non-state roads.

3.3.13. New York

The New York DOT provides guidance related to radar speed signs for work zone applications through an Engineering Instruction (44). Of interest in this guidance is the specification of the excess speeds that should trigger the device (5 mph for posted speed limits between 30 and 40 mph, 10 mph for speed limits above 45 mph). Also, the guidance indicates that devices should be deactivated during periods of traffic congestion. Finally, and most critical to the work being discussed in this document, it notes that overuse may result in desensitizing the public and lessening the effectiveness of the signage.

3.3.14. Vermont

The State of Vermont Agency of Transportation (VTrans) has established a policy for municipalities to install radar speed signs on state rights-of-way (45). Specifically, this document provides conditions where such signs should be used, as well as the technical requirements associated with them. This guidance specifies where radar speed signs are applicable (conditions of use). Locations listed include those where speed limits are being exceeded by a given speed threshold, transition or speed zones, and a high speed-related crash sites.

3.3.15. Massachusetts

While MassDOT does not provide specific guidance on radar speed signs, the Executive Office of Public Safety and Security (EOPSS) provides basic information related to trailer-based devices (46). This information is very general and does not discuss specifics such as physical placement in the roadway environment or permitting. Rather, it briefly discusses the effectiveness of such signage.

3.4. Summary

As these sections have shown, the agency documents that specifically discuss radar speed signs vary considerably. In some cases, notably the Federal MUTCD, the information provided is broad but covers the basics of radar speed signage (application, colors, etc.) well. In other cases, such as Arizona or Minnesota, this information is extensive. Finally, some states, such as Kentucky and Massachusetts, cite the usage of radar speed signs, but no formal engineering documentation provides any information or guidance regarding its application.

Based on the information presented in this chapter and Appendix B, a number of conclusions can be drawn. First and foremost, the provisions set forth in the California MUTCD serve as a foundation for the warrants to be developed later in this work. Specifically, as these guidelines are already in place, deviation from them is not feasible. Secondly, while much of the basic guidance provided by other states is similar to that of California's MUTCD in general (such as application settings), the level of detail and specificity varies widely. As a result, it would be difficult to reconcile the practices and guidance employed elsewhere into one cohesive approach to radar speed sign warrants. Based on the fact that California already presents baseline guidance related to radar speed signs, much of the guidance provided by other states can be considered informational and not necessary for further consideration in completing the work of this project. Finally, in examining state legal codes, it is clear that radar speed signs are not typically emphasized in legal code. Rather, most states adopt the MUTCD (or a state-specific edition) and rely on that document to provide guidance.

4. PRACTICIONER SURVEY

In order to develop warrants and specifications of use for California practitioners and communities, it was necessary to understand what equipment is currently used and what practices are employed throughout the state. To accomplish this, an online practitioner survey was distributed via organizations whose memberships consist of city and county engineers. Groups participating in the survey included Caltrans, the Southern California and Central Coast chapters of the American Public Works Association, the County Engineers Association of California and the League of California Cities. The membership of these groups represented a cross section of the entities that use radar speed signs.

In total, 63 persons completed the survey, with responses obtained from practitioners throughout California. As one might expect, the information provided by respondents indicates that equipment and practices currently employed vary across jurisdictions. The following sections summarize the results of the survey. Please note that many questions in the survey allowed for multiple responses, so the totals do not always add up to 63.

4.1.1. Use of Radar Speed Signs and Trailers

As expected, an overwhelming majority of respondents indicated that their community employed radar speed signage, trailers, or similar devices, either individually or at multiple sites. Exactly 59 respondent communities used such devices, while only four indicated that no devices were used.

4.1.2. Sign Devices Employed

Figure 4-1 illustrates the breakdown in both percentage responding and total number of responses pertaining to the specific types of devices employed by communities and agencies. As the figure indicates, the most common devices being used by communities are permanent radar speed limit signs and radar speed trailers. Permanent signs were used in 41 responding cases (68.3 percent of respondents), while radar speed trailers were used in 52 responding cases (86.7 percent of respondents). Portable signage (signs that can be affixed to a pole and removed for use at another location) was used by 10 respondents, while CMS signs equipped with radar were only used by seven respondents.

The widespread use of radar trailers should not be surprising, as they are portable and can be transported to any location where they are expected to be effective. One could surmise that as the technology of portable radar speed signs that can be mounted to and removed from ordinary poles gains more exposure and use, this device might surpass radar trailers in usage. Permanent installations will likely continue to be widely used, especially in school zones, where the need for speed control is a priority.

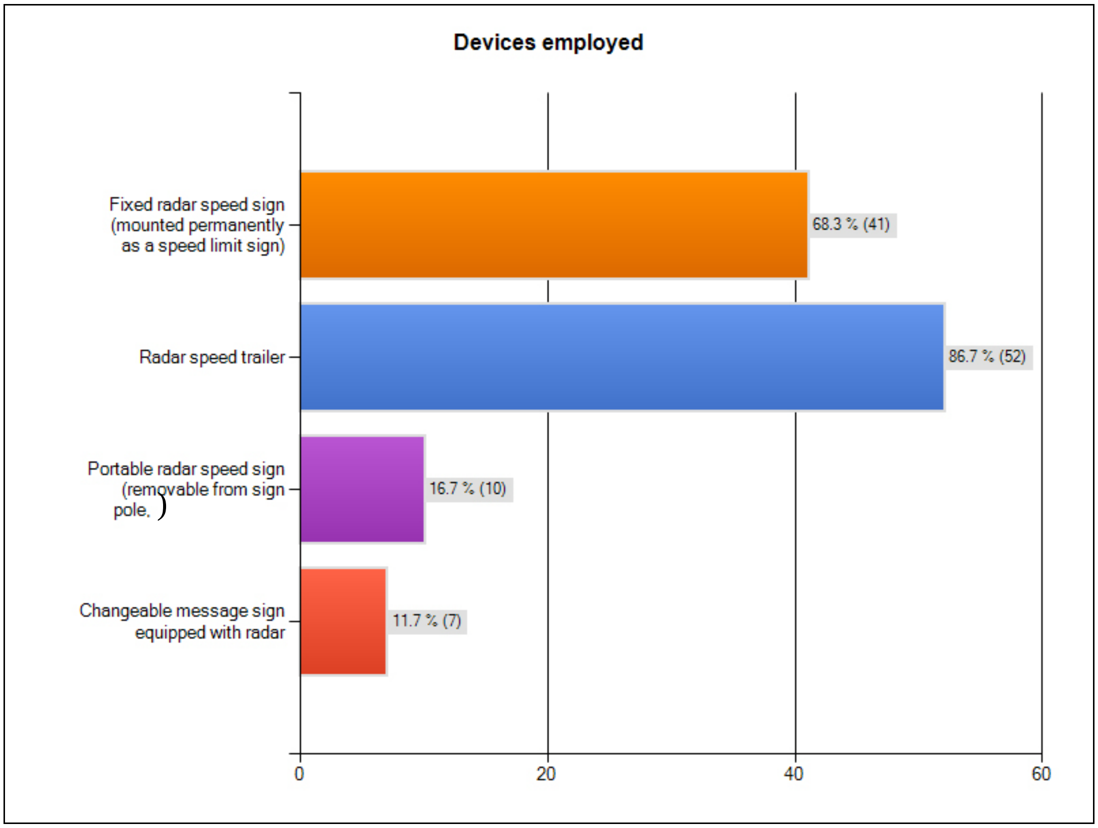

Figure 4-1: Sign devices employed

4.1.3. Application Type

Next, respondents were asked whether the device application was permanent or portable based on different location types. These types included school zones, work zones, residential areas, business districts, and other (representing applications that are not captured by the previous groups). Responses indicated that school zones were where most permanent devices were installed (30, or 61.2 percent), while other locations saw portable deployments predominantly. As one would expect, all respondents indicated that radar speed signage in work zones was portable. High percentages of portable deployments were also made in residential and business zones. Overall responses are presented in Table 4-1.

Table 4-1: Application type responses

	Permanent	Portable	Response Count
School zones	**61.2% (30)**	38.8% (19)	49
Work/construction zones	0.0% (0)	**100.0% (18)**	18
Residential neighborhoods	31.4% (16)	**68.6% (35)**	51
Business district	34.6% (9)	**65.4% (17)**	26
Other	**50.0% (11)**	**50.0% (11)**	22

4.1.4. Application Uses

Next, respondents were asked why radar speed signage was being used. Narrative responses, as expected, indicated the primary reason for sign deployment was related to observed speeding issues (43 respondents indicated speed in their response). Safety was also indicated in many responses (20) as were resident complaints about speeding and/or requests for such devices (24). Five respondents indicated that signage was also intended to serve as an educational or informational tool for drivers. Finally, deployments were also considered for special events, to address shortcutting issues, and to make the speed limit stand out to motorists in areas of roadside visual clutter. All responses obtained are presented in Appendix C.

4.1.5. Guidance Referenced

One of the primary goals of this project is the development of warrants for when radar speed signs should be used. To this end, respondents were asked if they referenced any formal documents (legal code, engineering guides, MUTCD, etc.) when considering sign deployment. Results indicated that only 12 respondents referenced any formal documents, while 47 did not. For those who answered affirmatively to consulting documentation, information regarding the specific reference was requested. Specific answers provided by respondents were as follows:

CA MUTCD for sign display color, sign legibility and visibility

County policy and the CaMUTCD

Legal/safe speed limit as determined by traffic study

MUTCD

Guidance from MUTCD

Local policy regarding safety issues regarding placement (level ground, not to close to traffic, etc.)

Criteria for deployment developed in-house

Devices are selected and placed per California Vehicle Code and MUTCD standards.

Speed survey conducted to determine actual speeding does occur

CA MUTCD

California Manual of Uniform Traffic Control Devices

Traffic speed study, Caltrans standards/specification, traffic control plan, trip generation study

As the feedback received indicates, a majority of respondents indicated that the California and/or Federal MUTCD were consulted. This is logical, as each document contains some form of guidance related to radar speed signs. Other references cited such as speed studies, while not guidance documents, do provide at least a basis for decision making. Of course, more concerning from the standpoint of this project are the 47 respondents who indicated that no formal documentation was consulted. While it is possible to assume that many of the deployments these respondents were familiar with at the very least employed speed studies to establish a need, the potential for random applications is also likely.

4.1.6. Manufacturer

Since the development of functional/electrical specifications is a key aspect of this project, it was of interest to find out what devices were currently used in respondent applications. To this end, respondents were asked the manufacturer of their deployments. The following is a summary of manufacturers identified and the number of respondents indicating ownership[6] (complete responses provided in Appendix A):

Information Display Co. (SpeedCheck, including the VSC 1820/L model that provided a basis for the specifications presented in Chapter 6) – 13

Fortel (V-Calm) – 13

3M – 7

RU2 – 3

Kustom Signals – 3

Radarsign – 3

U.S. Traffic Supply (National Signal) – 3

All Traffic Solutions – 3

Veritext – 2

IDL – 1

TAPCO – 1

K&K Systems – 1

MPH Industries – 1

Decatur Electronics – 1

[6] Note that a community may use multiple devices from different manufacturers. As a result, the total number of manufacturers exceeds the number of survey participants.

As these responses indicate, a significant number of communities are using products from Information Display Company and Fortel, with a small number using 3M products. These responses also provide an indication of the number of different manufactures that provide radar speed signs in some form. Despite the fragmented nature of radar speed sign vendors and their products, common functional and electrical specifications have been developed in this project.

4.1.7. Power Sources

How devices were powered was of interest for this work. Depending on the application, power may come from the electrical grid, from batteries, from solar panels, or from generators. A question was included in the survey to determine the power sources used. Results for this question are presented in Table 4-2.

Table 4-2: Power sources employed

Device	Connected to Grid	Battery Power (backup system)	Solar Power	Generator	Response Count
Fixed radar speed sign	56.4% (22)	23.1% (9)	**82.1% (32)**	0.0% (0)	39
Radar speed trailer	0.0% (0)	**66.0% (31)**	57.4% (27)	10.6% (5)	47
Portable radar speed sign	0.0% (0)	33.3% (3)	**77.8% (7)**	0.0% (0)	9
Changeable message sign	22.2% (2)	55.6% (5)	**88.9% (8)**	0.0% (0)	9
Other	**100.0% (1)**	**100.0% (1)**	**100.0% (1)**	0.0% (0)	1

It is interesting to note, specifically in the case of fixed signs, most respondents indicated solar as the power source employed, while only 55 percent indicated use of grid power. This is of interest because whether battery, solar or generator power were the primary sources of energy, a connection to the grid would assumed, if for no other reason than to serve as backup power. Aside from this finding, none of the information provided by respondents was unexpected.

In addition to indicating the power sources employed, respondents were also asked whether they had used or developed any functional/electrical specifications for their devices. Nearly all respondents indicated that they had not, or that they relied on manufacturer specifications/documentation. The only exception was the community of Sunnyvale, which provided extensive information that is presented in Appendix E.

4.1.8. Maintenance

Just as important as establishing functional and electrical standards, the maintenance required for radar speed signage must be considered. To better understand this aspect of the signage, respondents were asked to provide any information they may have regarding maintenance of their signage and lessons learned. Typically, most responses indicated the most significant problem was maintenance related to vandalism. However, some respondents indicated some items of interest related to functional and electrical aspects of the signage. These included:

Fortel signs currently do not have an internal clock, which makes programming in the field difficult. Current design has led to water damage to the internal hardware.

We do preventive maintenance on the signs at least twice a year, cleaning, calibrating, checking the clock and bulbs. We have not had too many issues with them except the solar ones having sufficient power to operate 24 hours. We have reduced the hours of operation for the signs to function properly.

The only issue we have had is with tree branches getting in the way of the solar panels.

Low maintenance required of Fortel model.

Low maintenance, need to recharge the battery after a day or two.

The batteries need to be replaced from time to time. Must be leveled and properly aligned with traffic at an unobstructed location. Easy to install.

The Decatur unit requires a tremendous amount of maintenance—look for simpler design in future purchases.

Low maintenance, but LEDs can fail, batteries can fail and are subject to low charge in persistent cloudy weather, water damage, programming takes time.

The radar speed trailers seem to require periodic maintenance. We have no issues with the fixed radar speed signs.

Low maint. plug in or charge batteries, clean solar panels.

RU2 traditionally heavy to install and requires removal of several screws to get to the main board; however, the unit is extremely legible in the sun. By far the Fortel brand is junk. The easiest to use is the Speed Check sign. Lightweight and easy to handle. Great display. Easy functionality.

We have had some problems with the solar units not working usually battery related.

High amount of maintenance for Fortel, less for Information Display. First few weeks will result in many service calls to the manufacturer for software glitches, clock issues, etc. Long-term issues are the same and also include malfunctioning LED modules.

The fixed radar signs do require regular maintenance and there have been some computer, battery and radar issues. Our biggest expense was the replacement of the radar unit after 2 1/2 years of use. We usually have the Fortel technician make a service call about every 2 years.

Battery replacement is costly.

Changeable message sign/radar has been maintenance intensive. It was an early generation sign and the first one in our District.

In general, the responses reveal a number of maintenance issues that would be expected, such as battery life and solar panel cleaning. However, the feedback also indicated that Fortel devices, which were identified as being used by a fair percentage of respondents, present maintenance issues in some communities (interestingly, note that some of the feedback presented also found Fortel to perform well).

4.1.9. Accuracy of Speeds

As the primary purpose of radar speed signage is to measure a motorist's speed, respondents were asked about their perceptions/observations of the accuracy of the speed measurements made by the radar equipment. Of the 58 respondents who indicated that their agency employed radar speed signs, 55 (95 percent) believed that the speed measurements made by the devices were accurate. The remaining three respondents (5 percent) believed the measurements made by the signs were not accurate.

Respondents were also asked whether any formal evaluations had been made for each sign. In general, mixed responses were provided, with only informal evaluations being made. Several respondents indicated that these informal evaluations consisted of speedometer comparisons (i.e., someone drove past and compared the speed displayed by the sign to what their speedometer indicated), radar speed gun comparisons, and through the use of tuning forks in calibration. Additionally, one respondent indicated that since the signage was not used for enforcement, formal evaluations were not made. In short, many respondents were aware of or conducted brief accuracy checks, but no formal, statistical-type evaluations were pursued in any case.

4.1.10. Impacts on Speeds

The primary intent of radar speed signs is to reduce motorist speeds where they are deployed. To this end, respondents were asked whether their community/agency had conducted any formal evaluation of whether speed reductions had occurred. A portion of respondents, 20 (35 percent), indicated that such evaluations had been made. A majority of respondents, 37 (65 percent), indicated that no evaluation of motorist speeds had been made following deployment. Specific information provided by respondents included:

At the school zone location, the County concluded that the Radar Speed Sign had a negligible effect on reducing vehicle speeds.

Speed studies conducted prior to, shortly after installation and 2 years after installation reveal negligible reductions in 85th percentile speeds.

They do result in slightly lower speeds when they are on. We only have them on during school commute time (before and after school)

There has been a slight reduction in speeds in some cases. They have been more effective when used in conjunction with a speed limit change when entering a community. Less effective when placed on a high speed road with no adjacent land use change.

On San Ysidro Rd in the Montecito area of the County of Santa Barbara the speed limit is 35 mph with a 25 mph school zone. During use of the sign we saw a 2 mph reduction in the 85th percentile.

Johnstonville School staff has evaluated the use of the radar signs in front of their school and is very pleased with the results

Variable depending on location

Prevailing speeds estimated to have been reduced for short term (3 months) by 1-2 mph on pole mounted

The local public likes it. The city council likes it and therefore, I like it.

Speed was reduced for the first 2 months and then started to return to normal

No formal evaluation. However, the public perception is that the 85th percentile is lower as a result of deployment

Our portable V-Calm sign is accessible on-line via a modem, which allows us to download speed and volume data at anytime. Observed results show reduction in 85th percentile speeds near the sign.

Signs reduced speeds initially, but speeds have climbed slightly since.

We have conducted a few before/after speed studies. The studies have indicated a slight reduction in speeds for the first few months after installation. Speeds seem to start going back up after a few months.

Conducted before and after speed survey indicating lower average speeding.

The reduction in speed for fixed radar speed signs is observed only for about the first six months. Afterwards the speeds creep back to what it was prior to installation.

Some reduction in speed levels

We saw a reduction of about 0.1 to 2 mph on a 40 mph street.

Initially yes, 85th dropped 1 to 2 miles. Have not done long term follow up. Units record all the data, so will eventually review.

November 2002—following installation of our first radar sign at a school zone, we found a compliance improvement of 32% more motorists traveling 35 mph or under during school zone hours.

In general, these responses seem to indicate that in most cases, an agency has seen some effect of lower speeds following sign deployment. Of course, responses also indicated that the signage has a negligible effect on lowering speeds, particularly longer-term. This would seem to indicate that the best approach toward the use of radar speed signs might be to pursue temporary deployments (trailers, portable signs, etc.), rather than the installation of fixed signage, which remains in place but loses effectiveness over time.

4.1.11. Impacts on Safety

In addition to the impacts on speeds that radar speed signs might have, their impacts on crashes was of interest. To this end, respondents were asked what if any safety evaluations had been performed at sites following sign deployment. A majority of respondents, 55 (95 percent), indicated that no evaluations had been made. Three respondents (5 percent) indicated that an evaluation of motorist speeds following deployment had been done. Specific information provided by these respondents included:

City wide Police Traffic Accident Report

No formal study. However, in the one location where a radar sign was deployed for safety reasons, accidents appear to have decreased.

The number of run off road collisions has gone down significantly at the location of the changeable message/radar sign on the curve.

As was found in the literature review, it is evident that the safety impacts of radar speed signs have not been evaluated in any significant fashion in any California community. Of course, this is not surprising as the primary purpose of the signage is to reduce speeds. As a result, the limited time and funds available for evaluations, even informal, would be spent looking at speed impacts. Still, lowering vehicle speeds should result in safety benefits, but at present those impacts remain undetermined.

4.1.12. Additional Information

To conclude the survey, respondents were asked if they had any additional information they would like to provide regarding their experience with radar speed signs. Responses included:

They appear to be highly desired by communities, although their effectiveness in reducing speeds is debatable.

Although we have not done any formal evaluation, I have observed that some vehicles did slow down after the sign displayed a speed that is well above the speed limit.

Majority of community are happy with the system

They have high maintenance cost, the communities love them, our work crews dislike them as they are in constant need for repairs or adjustments

They are particularly helpful in construction zones.

La Verne will be deploying permanently mounted driver feedback signs in school zones in Summer 2010.

Citizens always call and thank the department when they see the trailer in their neighborhood. There is at least a community perception the trailer has an effect on speed reduction

We are interested in permanent installation of a couple of signs on a highway in town that traverses a middle school.

The fixed radar unit has been vandalized in the past and received complaints that the lights bother residents at night.

The speed trailer has been very beneficial in addressing citizen complaints regarding speeding on residential streets.

Our preferred method is the speed signs with actual driver's speed being displayed to the driver.

It seems to keep the honest people honest. Those who are intent on speeding still do to a large extent.

Residents who have concerns about speeding are very appreciative to have the radar trailer deployed. From that viewpoint, it is a good tool to have.

The public highly supports the use of radar speed signs. However, their effectiveness and their acceptance by city staff would greatly improve if maintenance issues were addressed.

We purchased one 4 years ago (portable type, chained it to a large boulder) but within a week it was stolen. Council decided not to replace.

As these responses indicate, there are a variety of views and opinions regarding radar speed signs and their effectiveness. The perception of many respondents is that residents find the signage to be effective, even though it may not be reducing speeds in the long term. Of course, the signage has vandalism and maintenance drawbacks, but in general there seems to be a more positive acceptance of the devices compared to other approaches. This is likely due to the lack of an enforcement aspect.

4.1.13. Summary

This chapter has presented the results of a survey of California practitioners regarding the use of radar speed signage in their community or by their agency. In total, 59 of 63 respondents indicated that their community or agency uses or has used radar speed signs. Speed trailers and permanent signage were the two most typical deployments indicated. School zones hosted the majority of permanent deployments, while residential, commercial and work zones were the most prevalent applications of portable signs. The primary use of the signage was for speed control, as would be expected. In most cases, reference documents (e.g., MUTCD) were not consulted, although a few respondents indicated they consulted such documents.

Responses indicated that equipment from various manufacturers was currently being used. Solar power was the most common power source for deployments, followed by battery power. Of course, one could reasonably assume that many deployments, particularly those that are permanent, are also connected to the grid. In general, the responses revealed a number of maintenance issues that would be expected, particularly issues with vandalism, battery life and solar panel cleaning.

Regarding the speeds being measured and posted, many respondents were aware of or had conducted brief accuracy checks, but no formal, statistical-type evaluations were reported. Similarly, most respondents indicated that no formal evaluation of speed trends following deployment had been made. Also, no evaluations of the impact of signage on safety had been performed.

None of the information obtained from respondents conflicted with existing requirements in California (state legal code, MUTCD). In light of this, the information that respondents reported they had consulted (e.g., MUTCD) will be employed in the warrants and guidance developed.

5. WARRANTS AND GUIDANCE

This chapter presents warrants and guidance related to the deployment of radar speed signs under various conditions. Deployment applications discussed are those identified during the course of the literature review presented in Chapter 2 and in the California user survey presented in Chapter 4. Traditionally, radar speed signs have been deployed to address concerns in school zones, work zones, residential and commercial areas, and in general applications (speed transition zones, etc.). Based on the deployment applications identified, various warrants for when radar speed signs may be deployed were developed. *The discussion in this chapter does not constitute a standard, specification or regulation. It is not intended to replace existing Caltrans mandatory or advisory standards, nor the exercise of engineering judgment by licensed professionals. The document is simply a reference guide, which compiles information and concepts from various agencies and organizations faced with similar transportation issues. Caltrans acknowledges the existence of other practices and provides this document as a reference guide for those responsible for making professional engineering decisions.*

5.1. General Basis of Warranted Use

The development of warrants and guidance for the use of radar speed signage varies by the specific application. For example, the development of warrants related to the use of protected left turn signal phasing as opposed to permitted/protected phasing at signalized intersections would typically entail data collection activities and modeling at multiple sites. In the case of the warrants developed here, the varied distribution of potential sites, as well as different applications, precluded extensive site-based performance studies. Rather, existing study results and practitioner feedback were employed to develop general warrants related to the application of radar speed signs in California. The following paragraphs discuss the approach employed in developing warrants.

Consideration of the various application locations first had to be made. This was done through the literature review and practitioner survey portions of this work. Based on the general language of the California MUTCD, radar speed signage—at least on state-controlled roads—is permissible anywhere when used in conjunction with existing speed limit signage or advisory speed signage. Additionally, the use of radar speed signs in work zones is explicitly called for by the California MUTCD. Finally, the California MUTCD could be considered to allow the use of radar speed signs in school zones by permitting their use in conjunction with existing speed limit signage or advisory speed signage in the following passage: "Vehicle Speed Feedback Signs are appropriate for use with advisory speed signs and with temporary signs in temporary traffic control zones." A school zone may be considered such a temporary (in length) zone.

Based on this information, as well as the deployments discussed in past research, the applications to be considered by this work were identified. Identified applications of radar speed signs included addressing excessive mean and 85^{th} percentile speeds, safety concerns, traffic issues, posted speed compliance, pedestrian presence, school zones, work zones, residential and commercial applications, and general applications (speed transitions zones, signalized intersection approaches, etc.).

The next step in developing warrants was consideration of the factors and characteristics that may require the use of radar speed signs. In other words, in what specific cases should radar speed signs be used? In general, radar speed signage is employed when a speeding problem is identified or perceived. Another rationale for the use of radar speed signs is when an excess of speed-related accidents or pedestrian–vehicle collisions occur in a location. The argument could be made that the speed-related crashes are the result of an overall speeding problem rather than a separate problem involving crashes. Nonetheless, this could be considered an useful metric.

Once the various factors and characteristics associated with the historical applications of radar speed signs were identified, objective criteria that can be methodically applied in evaluating potential deployments were developed. These criteria were developed based on the results of prior research, which, overall, had focused on quantifying the problem (excessive speeding, crash occurrence), as well as the impact that the radar speed sign application had on it.

No examination of the impacts radar speed signage had on crashes was found in any literature, nor did the practitioners surveyed indicate any general observations. Instead, conservative criteria have been established by the researchers for practitioners to follow should they wish to use crash experience in warranting radar speed sign use. However, the predominant justification for using radar speed signs is a measured or perceived speeding problem. This application has been extensively examined, and that research has provided a foundation on which to build objective, measureable criteria. These criteria are primarily related to changes in mean speeds and 85th percentile speeds observed by various studies following deployment.

Based on the literature review and survey, two levels of guidance were developed for the use of radar speed signs. The first was general guidance. This level of guidance was developed to warrant the use of radar speed signs in addressing general concerns. For this type of guidance, criteria were developed for mean speeds, 85th percentile speeds, Average Daily Traffic (ADT), speed limit compliance issues, accident history, pedestrian presence, and posted speed limits.

The second level of guidance focused on location-specific applications of radar speed signage. This level of guidance was developed to warrant the use of radar speed signs in addressing concerns specific to different sites, such as school zones. To this end, criteria were developed to describe the characteristics of school and park zones, work zones and street conditions that would warrant the use of radar speed signs.

The format and presentation of the warrants is based on that issued by the City of Bellevue, Washington (47). This format was selected following input from Caltrans personnel. It concisely summarizes conditions for radar speed sign usage. The following sections provide the specific warrants developed for the different levels of guidance.

5.2. General Guidance

The following warrants apply to general cases where the application of a radar speed sign may be of interest. These general cases include excessive mean speed and 85th percentile speed issues, ADT levels, speed limit compliance issues, accident history, pedestrian presence, and posted speed limits. The application of these warrants should be made following the completion of appropriate engineering studies. These may include spot speed studies, traffic counts, accident investigations, or pedestrian counts/observations, depending on the application case. An overview on how to conduct a spot speed study is provided in Appendix D. The specific type of deployment (trailer-based, permanent sign, etc.) is at the discretion of the agency and will depend on the problem being addressed, power availability, and so forth. Note that footnotes related to the development of these warrants are provided for reader clarification following the table.

General Guidance

Criteria	Warrant
85th percentile speed	A radar speed sign may be considered when the observed 85th percentile speeds at a site exceed the posted speed limit by 5 mph or more (a).
Mean speed (b)	A radar speed sign may be considered when the observed mean speeds at a site exceed the posted speed limit by 5 mph or more (c).
Average daily traffic (ADT)	A radar speed sign may be considered when ADT exceeds 500 vehicles (d).
Accidents	A radar speed sign may be considered at sites exhibiting a correctable speed-related accident history within a recent time period (e).
Pedestrians	A radar speed sign may be warranted at sites with a pedestrian-related accident history.
Posted speed limit	A radar speed sign may be considered in conjunction with other warrants when the posted speed limit at a site is 25 mph or greater.

Footnotes

(a) The threshold of 5 mph has been established based on the nature of 85th percentile speeds. These speeds indicate the percentage of the traffic stream that is exceeding a given speed. In the case of this warrant, it is reasonable to expect that only a small proportion of vehicles will be traveling more than 5 mph over the posted speed limit if the posted speed limit was truly set at the 85th percentile speed. Note that mean speeds may fall below the posted speed limit at a site, but a speeding problem may still exist in the 85^{th} percentile.

(b) Typically, the 85^{th} percentile speed is employed by traffic engineers to determine the proportion of the vehicle population that is exceeding the speed limit. However, it is recognized that some of the users of this work may not be from the traffic engineering discipline. In that case, a mean speed warrant has been provided as such users may be more comfortable with that metric for their particular application.

(c) The threshold of 5 mph is recommended based on the observed impacts of radar speed signage in past applications. In general, the mean speed reduction produced by signs is between 1 and 12 mph. Consequently, it is logical to employ a minimum threshold for mean speeds exceeding the posted speed limit of 5 mph before the application of a radar speed sign should be considered.

(d) The threshold of 500 vehicles per day ADT is based on the variability of rural ADTs, which tend to be low. Note that a limited number of evaluations/applications were made for traffic levels below 1,000 vehicles per day. Most reported applications were made at sites with high ADT.

(e) The time period considered recent is at the discretion of the agency considering use of a radar speed sign.

5.3. Location-Specific Guidance

In addition to general guidance, information on specific past applications of radar speed signs made it possible to develop location-specific guidance in different cases. The following warrants apply to locations where the application of a radar speed sign may be of interest. These locations include school and park zones, work zones, and other roadway features including transition zones, in conjunction with curve warning signs, and signal approaches. The application of these warrants should be made following the completion of appropriate engineering studies such as spot speed studies. An overview on how to conduct a spot speed study is provided in Appendix D. The specific type of deployment (trailer-based, permanent sign, etc.) is at the discretion of the agency and will depend on the problem being addressed, power availability, and so forth. Note that footnotes related to the development of these warrants are provided for reader clarification following the table.

Location-Specific Guidance

Schools and parks	A radar speed sign may be considered for use within one half (1/2) mile of a school zone or park (a), and
	A radar speed sign may be considered when the posted speed limit in a school zone or park area is 15 mph or greater (b), and
	• A radar speed sign may be considered when the 85th percentile speeds in a school zone or park area exceed the posted speed limit by 5 mph or more (c), or • A radar speed sign may be considered when the observed mean speeds in a school zone or park area exceed the posted speed limit by 5 mph or more (d, e), or • A radar speed sign may be considered when ADT exceeds 500 vehicles (f), or • A radar speed sign may be considered to supplement a conditional speed limit already in place (e.g., a sign stating: Speed Limit 25 when Children Present)
Street conditions (g)	Transition zones—A radar speed sign may be considered in conjunction with other warrants where a speed transition zone exists (high to low speed limits).
	Curve warning—A radar speed sign may be considered in conjunction with other warrants where a curve speed warning advisory sign exists (high to low speed).
	Signal approach—A radar speed sign may be considered in conjunction with other warrants for high-speed signalized intersection approaches where the speed limit exceeds 45 mph (h).
Work zones	A radar speed sign may be considered when the posted speed limit in a work zone is 35 mph or greater (i), and
	• A radar speed sign may be considered when the observed mean speeds in a work zone exceed the posted speed limit by 10 mph or more (j). • A radar speed sign may be considered when the observed 85th percentile speeds in a work zone exceed the posted speed limit by 10 mph or more. • A radar speed sign may be considered when there have been speed-related accidents in a work zone

Footnotes

(a) The threshold of a half-mile proximity is based on the criteria employed in past sign applications.

(b) The threshold of a posted speed limit of 15 mph is based on the minimum reported posted speed limit of past sign applications.

(c) The threshold of 5 mph has been established based on the nature of 85th percentile speeds. These speeds indicate the percentage of the traffic stream that is exceeding a given speed. In the case of this warrant, it is reasonable to expect that only a small proportion of vehicles will be traveling more than 5 mph over the posted speed limit if the posted speed limit was truly set at the 85th percentile speed.

(d) The threshold of 5 mph is recommended based on the observed impacts of radar speed signage in past applications. In general, the mean speed reduction produced by signs is between 1 and 12 mph. Consequently, it is logical to employ a minimum threshold for mean speeds exceeding the posted speed limit by 5 mph before the application of a radar speed sign should be considered.

(e) Typically, the 85^{th} percentile speed is employed by traffic engineers to determine the proportion of the vehicle population that is exceeding the speed limit. However, it is recognized that some of the users of this work may not be from the traffic engineering discipline. In that case, a mean speed warrant has been provided as such users may be more comfortable with that metric for their particular application.

(f) The threshold of 500 vehicles per day ADT is based on the variability of rural ADTs, which tend to be low. Note that a limited number of evaluations/applications were made for traffic levels below 1,000 vehicles per day. In general most reported applications were made at sites with high ADT.

(g) Caltrans policy is that radar speed signs must be placed below the permanent (black on white) speed limit sign in such applications.

(h) The threshold of a posted speed limit of 45 miles per hour is based on the minimum reported posted speed limit of past sign applications.

(i) The threshold of a posted speed limit of 35 miles per hour is recommended to include lower speed work zones.

(j) The threshold of 10 mph is recommended based on the observed impacts of radar speed signage in past work zone applications. In general, the mean speed reduction produced by signs is between 1 and 12 mph. Consequently, it is logical to employ a minimum threshold for mean speeds exceeding the posted speed limit of 10 mph before the application of a radar speed sign should be considered.

5.4. Placement Guidance

Guidance related to the placement of radar speed signs is necessary in order to ensure that they are not a roadside hazard to vehicles. The intention of this guidance is to also move away from the random placement of radar speed signs to a more systematic approach. The placement of radar speed signs will vary according to factors such as the speed limit of the roadway, the roadside environment and the specific application. The following sections provide guidance on sign placement.

5.4.1. General Placement

In general, radar speed signs should be placed in positions where they will convey their messages most effectively without restricting lateral clearance or sight distances. According to the California MUTCD (31), signs should have a maximum practical clearance from the edge of the traveled way for the safety of vehicles. Normally, signs should not be closer than 6 ft (1.8 m) from the edge of a paved shoulder; if no shoulder is available, the minimum lateral distance is 12 ft (3.7 m) from the edge of the travel lane. The exception would be radar speed trailers, which represent a more substantial roadside obstacle. Trailer deployments should be farther from the edge of the pavement or shoulder. This distance will vary but should be no less than the baseline clearances set forth by the California MUTCD.

The following exceptions may also be applied in urban areas to all radar speed signs. A clearance of not less than 2 ft from the face of the curb may be used; a clearance of 1 ft (0.3 m) from the curb face may be employed where sidewalk width or existing poles close to the curb limit available placement space.

5.4.2. Trailer-Based Speed Sign Placement in Work Zones

While the California MUTCD does not provide specific guidance regarding trailer-based signage placement in work zones, a literature search found that the Maryland State Highway Commission does provide such guidance. This guidance may be applied to California applications as appropriate, provided all other existing work zone signing requirements are followed. Maryland's guidance on the placement of trailer-based signage includes the following (48):

- A radar speed trailer should be placed upstream of the work zone location.
- To maintain speed reductions throughout the work zone, more than one radar speed trailer should be used in work zones longer than one mile.
- The radar speed trailer should be placed and aligned to provide maximum legibility.
- If two radar speed trailers are used, they should be placed on the same side of the roadway and be separated by at least 1,000 ft.
- The display should be visible from ½ mile under both day and night conditions.
- Radar speed trailers should not be used on highways with three or more lanes in one direction.

Aside from these general guidance items, the physical placement of the radar speed trailer itself should follow existing California guidance related to the placement of signage within work zones. This will vary from project to project depending on conditions.

5.4.3. Portable Changeable Message Sign Placement in Work Zones

When a Portable Changeable Message Sign (PCMS) radar combination is used in work zones, specific placement guidance should be considered. Once again, guidance from the state of Maryland provides a baseline for placement (48):

- When multiple PCMS are used, the signs shall be placed on the same side of the roadway.

PCMS with speed display should be placed in advance of the work zone location.
Long work zones (i.e., one mile or longer) may warrant the deployment of 2 or more PCMS.
Due to the large size of the display panel, PCMS should be installed only where shoulder space allows sufficient room for setup outside of the travel way.
While PCMS with speed display may be used on all types of highways and work zones, either in rural or urban environments, PCMS deployment is particularly recommended for rural and urban multi-lane divided high-speed roadways.

The California MUTCD suggests that if a PCMS trailer is located within 15 ft (4.6 m) of the edge of the traveled way, it should be delineated with a taper consisting of nine cones placed at a spacing of 25 ft (7.5 m) apart.

In terms of visibility, the California MUTCD states that the message displayed on PCMS shall be visible from a distance of 1500 ft (460 m) and shall be legible from a distance of 750 ft (230 m), at noon on a cloudless day by persons with vision of or corrected to 20/20. On local roads, the message displayed on PCMS should be visible from a distance of 1500 ft (460 m) and should be legible from a distance of 750 ft (230 m), at noon on a cloudless day, by persons with vision of or corrected to 20/20 (31).

Aside from these general guidance items, the physical placement of the PCMS itself should follow existing California guidance related to the placement of message signs in work zones. This will vary from project to project depending on conditions.

5.4.4. Placement of Permanent Radar Speed Signs

Permanent radar speed signs are typically used in conjunction with existing posted speed limit signs. As such, the radar speed sign may be mounted below the speed limit sign on the same post. In some cases, because of the need for power and additional support, an entirely new post, speed limit sign and radar speed sign may be required. In such instances, the new installation would replace an existing speed limit sign. The location of this original sign would already follow current placement guidance and conventions. In the case of an entirely new location (i.e., no existing sign present on-site), the same placement guidance would apply.

The placement of permanent radar speed signs (and any associated solar panels) should not obstruct speed limit signs. The radar should face oncoming traffic at an appropriate angle (specified by the manufacturer) (47). Finally, the radar sign should be installed at a minimum height of seven feet from the base of the sign pole to discourage vandalism.

5.5. Summary

This chapter has presented warrants and guidance related to the deployment of radar speed signs under various conditions. Warrants were developed using results of the literature review and survey. Based on the language of the California MUTCD, radar speed signage was determined permissible anywhere when used in conjunction with existing speed limit signage or advisory speed signage (i.e., general placement locations). The problems that radar speed signs were typically employed to address included excessive mean and 85^{th} percentile speeds, safety concerns, traffic issues, posted speed compliance, pedestrian safety, and speed issues for vehicles in school and work zones, and residential and commercial areas. They were also used for more general applications such as speed transition zones, signalized intersection approaches, etc.

Two levels of guidance were developed for the use of radar speed signs. The first was general guidance, which included warrants related to mean speeds, 85th percentile speeds, ADT, speed limit compliance issues, accident history, pedestrian presence, and posted speed limits. The second level of guidance focused on location-specific applications of radar speed signage, which included school and park zones, locations where street conditions such as transition areas, curves, etc., were a concern, and work zones.

In addition to the development of warrants related to radar speed sign use, guidance on the placement of radar speed signs was developed to ensure that signage would not be a roadside hazard to vehicles. The intention of this guidance was to also move away from the random placement of radar speed signs to a more systematic approach. In general, radar speed signs should be placed in positions where they will convey their messages most effectively without restricting lateral clearance or sight distances. The California MUTCD (31) specifies that general static signs should not be closer than 6 ft (1.8 m) from the edge of a paved shoulder; if no shoulder is available, the minimum lateral distance is 12 ft (3.7 m) from the edge of the travel lane. Logic dictates that, in most applications, radar speed signs may be placed in a similar fashion. The exception would be radar speed trailers, which represent a more substantial roadside obstacle. Such deployments should be farther from the edge of the pavement or shoulder. Variations of this guidance were also provided for work zone applications.

6. SPECIFICATIONS

In addition to establishing when radar speed signs may be warranted, it was necessary to develop physical, functional and electrical specifications for radar speed signs. The intent of these specifications is to guide future purchases and deployments, taking into account the unique circumstances of a jurisdiction. *The discussion in this chapter does not constitute a standard, specification or regulation. It is not intended to replace existing Caltrans mandatory or advisory standards, nor the exercise of engineering judgment by licensed professionals. The document is simply a reference guide, which compiles information and concepts from various agencies and organizations faced with similar transportation issues. Caltrans acknowledges the existence of other practices and provides this document as a reference guide for those responsible for making professional engineering decisions.*

6.1. Development of Specifications

The specifications discussed in the following sections are based on investigation of the commercial radar sign models identified in the practitioner survey. The product data sheets were reviewed when available. The most important parameters, from an electrical and mechanical engineering perspective, identified in the data sheets were included in the specifications presented here. Note that most manufacturers only provided marketing brochures, which they presented as data sheets. These brochures contained little data that would allow for a thorough comparison of radar speed signs. However, a few companies, including 3M, Decatur Electronics, and National Signal, Inc., did provide reasonably complete data sheets. In addition to product brochures and specification sheets, the radar sign specifications developed by Caltrans District 1 and the community of Sunnyvale, California, served as a guide for this report.

6.2. Common Permanent Sign Specifications

This section presents specifications related to permanent radar speed sign devices. The specifications presented in this section may also be applied to portable post-mounted signs as appropriate (excluding topics such as solar panels, wiring connections to the power grid, etc.). A table of common sign specifications for pole-mounted radar signs is included in Appendix F.

6.2.1. General Description

A radar speed sign typically consists of two sections: one static and the other dynamic. The static display section is positioned above the dynamic section and displays the legend “YOUR SPEED” in letters 5” to 8” tall. Letters are generally black on a white background, although the background may be fluorescent yellow-green, fluorescent orange or yellow. The dynamic section is housed in a weatherproof cabinet and displays radar-measured vehicle speed in amber LED numerals 12” to 22” tall. The amber LED numerals are displayed on a black background for optimum visibility. Visibility is also optimized by the use of photocells to adjust brightness as the ambient light changes. The LEDs can be set to maximum brightness by the user.

An internally installed Doppler radar uses Digital Signal Processing to measure speeds from 5 to 100+ mph with +/- 1 mph accuracy. Speed displays have several modes from steady to flashing to blank that can be set by the user for various applications. Several user-settable display speed thresholds are typically available, such as minimum display speed, posted speed limit, excessive speed, and maximum display speed. The speed display is generally updated every second to provide dynamic feedback to the driver. A data logger that records speed data and sign parameters for download may be part of a radar speed sign system. The data may be downloaded to a memory device such as a secure digital (SD) card or transmitted wirelessly to a Personal Digital Assistant (PDA) or laptop through a secure BlueTooth™ or WiFi communications link. Some radar speed signs can be configured from up to 30 feet away through the secure wireless link.

The display window and housing must be highly vandal and impact resistant, and internal components should be modularly designed for easy accessibility and efficient in-field repair without removal from the mounting post.

6.2.2. General Specification

The radar speed sign shall not exceed 36 inches in width, 48 inches in height and 12 inches in depth. The display must be highly resistant to damage from thrown or launched projectiles. The display window shall be ¼-inch minimum thickness shatter-resistant polycarbonate. The display and/or electronics enclosure shall be ventilated NEMA 3R compliant, or better. Use of a ventilated NEMA 3R compliant electronics enclosure requires any electronic boards be conformal coated.

The display housing shall be fabricated from 11 gauge welded aluminum or comparable specification steel at a minimum. The sign shall weigh no more than 40 pounds, excluding batteries and PV panels. The radar sign's operational temperature shall be -30° to 60° Celsius (-22° to 140° Fahrenheit) at a minimum. Only brass and stainless steel tamper-proof fasteners shall be employed in sign fabrication. The sign exterior shall be powder coated with seaside environment quality materials and processes. The display shall be wind load rated at 100 mph when installed to the manufacturer's specifications.

The display housing shall have a label with the manufacturer's name, model number, serial number, date of manufacture and the rated voltage, current, power and volt-amperes, if applicable, permanently attached to the unit. The radar speed sign shall be mounted one inch below a regulatory speed limit sign as seen in the Figure 3.

Figure 2: Permanent Speed Sign Example (Image courtesy of Ian Turnbull)

6.2.3. Display

The radar speed sign shall consist of a static display section and a dynamic numeric display section. The static display section shall be positioned directly above the dynamic section and display the legend "YOUR SPEED" in letters 6 inches tall. The letters shall be black on a white background.

The numeric display shall consist of two 7-segment amber LED numerals. Each segment shall consist of 16 discrete LEDs, minimum, which are independently pointed to provide even light distribution within the viewing area. The LEDs shall be Institute of Transportation Engineers (ITE) amber in color, shall have a wavelength from 590 to 600 nanometers and utilize AlInGaP or better technology. The LEDs shall be rated for a life of 100,000 hours or more of continuous illumination. The LEDs shall provide a minimum luminous intensity of 2500 cd on the optical axis and a maximum intensity of 100 cd at 15 degrees horizontal from the axis (49)[7]. LED signal modules shall meet or exceed 85 percent of the standard light output after 48 months of continuous use over the temperature range. The numeric display shall have extremely high contrast with the background to provide the highest visibility.

Numerals shall be 18 inches tall. All sign system functions shall be controlled by a dedicated on-board removable solid-state computer. The numeric display range shall be 0 to 99 mph, with two numerals from zero to nine. The numeric display shall be capable of showing the speed of an approaching vehicle or a "blank-out" display, which has no visible speed or message. The display shall have a user-settable smooth analog-like dimming capability to optimize visibility and shall be capable of automatic dimming to adjust to ambient light conditions. The ambient light photo sensor for automatic dimming shall be shielded from extraneous light. To avoid

[7] Note: Many of the display specifications presented in the remainder of this chapter are based on the information provided by this reference.

distracting motorists, the display shall be principally viewable only within an area of maximum included angle of 30 degrees from the roadside. The display shall update once per second at a minimum to provide dynamic feedback to the driver.

6.2.4. Controller

The controller shall be a removable on-board dedicated solid-state microcomputer. The Operation Modes discussed in later sections shall be provided such that each mode can be set based on time-of-day. Modes shall be programmable via RS-232 hardwire and/or a secure wireless connection such as WiFi or BlueTooth™. See Section 6.2.6 for minimum security requirements.

A Windows Mobile PDA device, such as Pocket PC, and a Windows application shall be used for programming. The controller shall have a minimum of five (5) programmable shutdown/operational times per day, settable by day of week.

The controller shall have a smooth analog type dimming capability. Dimming shall have a 5–99 selection setting (5 = 5 percent of full bright, or very dim for night use). This setting shall be programmable via RS-232 hardwire and/or Wi-Fi connectivity through a Windows Mobile PDA device such as Pocket PC and through Windows desktop applications.

The controller shall incorporate a separate real-time clock backup power supply to maintain on-board clock settings in the event of a power failure. The controller shall store programmed settings and schedules in non-volatile memory. The controller shall default to last settings on power up.

The controller shall have a programmable speed threshold that allows a user to adjust the "YOUR SPEED" trip point. Threshold adjustments shall be in 1 mph increments and the range shall be 1–99 mph. The controller shall provide a "blank out" display at a programmable maximum vehicle speed.

6.2.4.1. Speed Thresholds

There shall be a minimum of four programmable speed thresholds: minimum display speed, posted speed limit, excessive speed, and maximum display speed. No speed should be displayed below the minimum display speed to limit non-vehicle signals. Posted speed limit is set to alert drivers that they are travelling over the speed limit. Excessive speed is set typically 5 to 10 miles per hour over the posted speed limit for additional attention. No speed or the maximum value is displayed above the maximum display speed to limit drivers "racing" the speed display.

6.2.4.2. Modes

The display shall have a selectable feature to set the numeric value for constant, blank, flash or stay at maximum value, when the detected speed is higher than the minimum display speed. An independent display mode shall be adjustable for each of the three speed thresholds above the minimum display speed.

6.2.5. Radar Unit

The radar unit shall measure the speed of approaching vehicles only and shall not display the speed of traffic traveling in the opposite direction. In multiple lane settings, where multiple vehicles may be approaching, the displayed speed reading must be consistent and not present multiple speeds for the same vehicle. The radar unit shall be impervious to moisture and factory set for the required application. The radar component shall be an internal, low power, K-band FCC part 15 certified, license-free unit.

6.2.6. Communications

A BlueTooth™ or WiFi wireless and RS-232 or USB hardwire connection to the controller shall be provided using a Windows programming unit. The Windows programming unit shall be a BlueTooth™ or WiFi-ready mini-laptop or similar device. The unit shall be provided with communications/interface software and a communication cable. The communication ports shall allow uploading and downloading of controller data. Data shall include firmware updates, time of day, special events, master shutdown, peak speeds, counts, maintenance, defaults and mode operation data and reports. If removable flash memory is used for data storage the minimum size shall be 4 gigabytes (GB).

Any configuration or data access shall require a strong password. BlueTooth shall be v2.1 or higher and the default security settings shall be changed. WiFi shall utilize WPA security at a minimum. Serial RS-232 or USB ports shall have restricted physical access. A strong password shall consist of eight characters minimum utilizing both characters and symbols.

6.2.7. Power Source

The sign system shall be powered by 12VDC valve-regulated absorbed glass mat (VR-AGM) battery. The battery shall be charged by photovoltaic (PV) panels or 120VAC grid power. The radar sign system shall have surge protection to withstand high repetition noise transients stated in Section 2.1.6 of NEMA Standard TS-2 (50).

6.2.7.1. Solar Charging

A solar charged system shall be sized to provide sign operation for 24 hours a day, 7 days a week, 365 days a year sign operation in the deployed environment. A solar charged system consists of a battery, PV panel and solar charge controller.

A minimum solar charged system shall consist of a 104 amp hour (Ah) AGM battery, 43 watt PV panel and a 3.25 amp (A) 12 volt solar charge controller. The battery shall be sized to provide power during the longest no/low solar radiation period. The PV panel shall be-sized to provide at least 10 times the average rated current draw of the display system (51). The solar controller shall be sized at 125% of the PV panel wattage rating and provides overcharge protection, improves charge quality and prevents battery discharge during low light conditions (52). Detailed design assumptions, conditions, and calculations are provided in Appendix F.

Standard practice is to protect a system's power source with a fuse or circuit breaker; in this case there are two power sources, the PV panel and the battery. Typically the PV panel fuse is located at the panel and sized at 150% (53) of the panel's short circuit current or 1.5 x 2.65A = 4.0 A for the Kyocera panel. The battery fuse is located at the battery and sized at 150% of the maximum battery charging current which is the same 4.0 A in this case.

6.2.7.2. AC Grid Power Charging

A minimum grid power charging system shall consist of a 24Ah AGM battery and a 6A 12 volt regulated battery charger. The battery charger shall be capable of utilizing 120VAC and 240VAC input. Detailed design assumptions, conditions, and calculations follow.

The battery shall be sized to provide sign power for one day during a grid power outage. An example for calculating charging is presented in Appendix F. The charger shall be a 3-Step regulated charger utilizing bulk, absorption and float charging techniques, appropriate for the battery type. The integral 3-Step regulated charger shall use temperature compensation. The charger must prevent destructive discharge and overcharge.

6.2.8. Installation

The sign assembly shall be installed on a Type 15 standard (54) with a Type 30 slip-base plate (55). Any pole height adjustments shall be from the top, and the pole top shall be recapped. The sign support shall be constructed in accordance with the details shown on the plans and Section 56-4, "Roadside Signs," of the Standard Specifications (56). The sign shall be installed in accordance with RS1, “Roadside Signs” of the 2006 Standard Plan (57).

Sign support and mounting hardware for the application shall be provided. The supports and mounting hardware shall conform to State Standard Specifications, Section 86 4.08, Signal Mounting Assemblies or an approved equal (58). The equipment shall be lightning surge protected utilizing a 5/8” diameter, eight foot ground rod and No. 6 AWG solid bare copper wire.

6.2.8.1. Solar Charging

When solar charging is employed, the PV panel shall be mounted 12” above the sign assembly, minimum, either on top or on the side of the pole. The PV panel shall be oriented due south with an elevation angle of 40 degrees from vertical. The connection between PV panel and the battery cabinet shall utilize Liquid-Tite flexible conduit. A minimum of 15 feet of conduit and 20 feet of cabling shall be provided per sign. The cable shall be 14 gauge or larger to stay within acceptable cable voltage loss for a 20 foot cable length of 3% - 5% (59) for 3.13A current. The battery cabinet shall be 14”x14”x8” (HxWxD) minimum, rated NEMA 3R, rated for a 70 pound load minimum and pole mountable.

Note if the installation is only utilized in summer or winter, performance will be improved by adding or subtracting approximately 15° of tilt, respectively.

6.2.8.2. AC Grid Power Charging

When grid power charging is employed the connection between sign cabinet and the battery cabinet shall utilize Liquid-Tite flexible conduit. A minimum of 5 feet of conduit and 7 feet of cabling shall be provided per sign. The cable shall be 18 gauge or larger to stay within acceptable 7 foot cable voltage loss of 3% for 3.13A current. The battery cabinet shall be 12 inch x12 inch x7 inch (H x W x D) minimum, rated NEMA 3R, rated for 25 pounds minimum and pole mountable. An example of such a cabinet and installation is shown below.

Figure 3: Example of Grid Charged Sign Installation (Image courtesy of Ian Turnbull)

6.2.9. Warranty

Warranties shall conform to Section 86-1.05, "Warranties, Guaranties and Instruction Sheet," of the Standard Specifications (58). The sign manufacturer shall provide a written warranty and support against defects in materials and workmanship at no cost to the State for a period of two (2) years from operational acceptance/activation. The sign manufacturer shall provide support to the State within twenty-four (24) hours of receipt of a request for information or assistance during the warranty coverage period. Sign replacement within the warranty period shall be provided within ten (10) working days after receipt of failed sign at no cost to the State. Warranty documentation shall be given to the Project Engineer before installation.

6.2.10. Options

6.2.10.1. Data Logging

A data logger shall record the peak speed with a month, day, year, hour, minute and second stamp in user-defined periods or bins. The data logger shall be capable of storing a minimum of 4 million data points. The logged data shall be downloadable through a serial cable, modem or wireless connection to a PDA or laptop. The logged data shall be formatted such that the information can be easily imported into a Microsoft Excel-compatible spreadsheet for processing and analysis. The sign shall also be capable of logging vehicle speeds when the display is "blanked out."

6.2.10.2. Global Positioning System (GPS)

A GPS unit may be incorporated to allow the system to automatically adjust date and time settings and enable sign coordinates to be accessed remotely.

6.2.11. Compliance

A Certificate of Compliance from the manufacturer shall be provided by the contractor to the Engineer certifying that the sign and any optional equipment comply with the requirements of any specifications employed and is in conformance with Section 6-1.07, “Certificates of Compliance,” of the Standard Specifications (58).

6.3. Common Trailer-Mounted Sign Specifications

This section presents specifications related to trailer-mounted radar speed sign devices. A table of common sign specifications for trailer-mounted radar signs is included in Appendix F.

6.3.1. General Description

A trailer-mounted radar speed sign typically consists of the trailer, a regulation speed limit sign installed on a foldable mount, a lockable cabinet and a solar panel. The trailer is usually a powder-coated, single-axle design with leaf-spring suspension and a 2 inch ball coupler. The sign usually has three parts: a regulation speed limit sign above a “Your Speed” legend with the measured speed displayed in amber numerals at the bottom. The lockable cabinet houses batteries for primary or supplemental power and may have a separate storage area. The solar panel is mounted above the speed limit sign for best efficiency.

The sign speed display section typically consists of two sections: one static and the other dynamic. The static display section is positioned above the dynamic section and displays the legend “YOUR SPEED” in letters 5 inches to 8 inches tall. Letters are generally black on a white background although the background may be fluorescent yellow-green, fluorescent orange or yellow. The dynamic section is housed in a weatherproof cabinet and displays radar-measured vehicle speed in amber LED numerals 12 inches to 25 inches tall. The amber LED numerals are displayed on a black background for optimum visibility. Visibility is also controlled by the use of photocells to adjust brightness as the ambient light changes. The LEDs can be set to maximum brightness by the user.

An internally installed Doppler radar uses Digital Signal Processing to measure speeds from 5 to 100+ mph with +/- 1 mph accuracy. Speed displays have several modes, from steady to flashing to blank, that can be set by the user for various applications. Several adjustable display speed thresholds are typically available, such as minimum display speed, posted speed limit, excessive speed, and maximum display speed. The speed display is generally updated every second to provide dynamic feedback to the driver. A data logger that records speed data and sign parameters for download may be part of a radar speed sign system. The data may be downloaded to a memory device such as an SD card or wirelessly to a PDA or laptop through a secure BlueTooth™ or WiFi communications link. Some radar speed signs can be configured from up to 30 feet away through the secure wireless link.

The display window and housing must be highly vandal and impact resistant and internal components should be modularly designed for easy accessibility and efficient in-field repair without removal from the trailer.

6.3.2. General Specification

The radar speed sign shall not exceed 36 inches in width, 48 inches in height and 12 inches in depth. The display must be highly resistant to damage from thrown or launched projectiles. The display window shall be 1/4-inch minimum thickness shatter-resistant polycarbonate. The display and/or electronics enclosure shall be ventilated NEMA 3R compliant, or better. Use of a ventilated NEMA 3R compliant electronics enclosure requires any electronic boards be conformal coated.

The display housing shall be fabricated from 11 gauge welded aluminum or comparable specification steel at a minimum. The display shall weigh no more than 40 pounds. The radar sign's operational temperature shall be -30° to 60° Celsius (-22° to 140° Fahrenheit) minimum. Only brass and stainless steel tamper-proof fasteners shall be employed in sign fabrication. The sign exterior shall be powder coated with seaside environment quality materials and processes.

The display housing shall have a label with the manufacturer's name, model number, serial number, date of manufacture and the rated voltage, current, power and volt-amperes, if applicable, permanently attached to the unit. The radar speed sign shall be mounted one inch below a regulatory speed limit sign.

6.3.3. Trailer

The trailer shall be a single-axle bumper pull with a 2-inch Class I or higher ball coupler, leaf-spring suspension and UV-resistant powder coat white or orange paint. The trailer shall include a lockable weatherproof steel storage box. The display shall be mounted on foldable or collapsible see-through design supports with gas-lift strut assist or better. Maximum trailer width shall be 84 inches and weight not more than 1,000 pounds. The trailer shall have adjustable leveling jacks at each corner. Wheels shall be standard four- or five-hole, 13-inch to 15-inch trailer wheels with the appropriate special trailer-rated trailer tires. The trailer shall meet all U.S. DOT safety standards for highway use.

Trailer options may include a removable tongue, lockable storage cabinet, locking lug nuts, torsion-spring suspension, trailer cover, spare tire, alarm system, electric leveling jacks, and chains near the wheels to stop wheel rotation when deployed in the field.

6.3.4. Display

The radar speed sign shall consist of a static display section and a dynamic numeric display section. The static display section shall be positioned directly above the dynamic section and display the legend "YOUR SPEED" in letters 6" tall. The letters shall be black on a white background.

The numeric display shall consist of two 7-segment amber LED numerals. The LEDs shall be ITE amber in color, shall have a wavelength from 590 to 600 nanometers and utilize AlInGaP or better technology. The LEDs shall be rated for 100,000 hours or more of continuous illumination. The LEDs shall provide a minimum luminous intensity of 2500 cd on the optical axis and a maximum intensity of 100 cd at 15 degrees horizontal from the axis. LED signal modules shall meet or exceed 85 percent of the standard light output after 48 months of continuous use over the temperature range. The numeric display shall have extremely high contrast with the background to provide the highest visibility.

Numerals shall be 18 inches tall. All sign system functions shall be controlled by a dedicated on-board, removable solid-state computer. The numeric display range shall be 0 to 99 mph, with two numerals from zero to nine. The numeric display shall be capable of showing the speed of an approaching vehicle or a “blank-out” display, which has no visible message. The display shall have an adjustable, smooth analog-like dimming capability to optimize visibility and shall be capable of automatic dimming to adjust to ambient light conditions. The ambient light photo sensor for automatic dimming shall be shielded from extraneous light. To avoid distracting motorists, the display shall be principally viewable only within an area of maximum included angle of 30 degrees from the roadside. The real-time display shall update once per second at a minimum to provide dynamic feedback to the driver.

6.3.5. Controller

The controller shall be a removable on-board dedicated solid-state microcomputer. Its operation modes, discussed in the following, shall be provided such that each mode can be set based on time of day and shall be programmable via RS-232 hardwire and/or a secure wireless connection such as Wi-Fi or BlueTooth™. See Section 6.3.7 below for minimum security requirements.

A laptop or Windows Mobile PDA device, such as Pocket PC, and a Windows application shall be used for programming. The controller shall have a minimum of five (5) programmable shutdown/operational times per day that can be set by day of week.

The controller shall have a smooth analog-type dimming capability. Dimming shall have a 5–99 selection setting (5 = 5 percent of full bright, or very dim for night use). This setting shall be programmable via RS-232 hardwire and BlueTooth™ or Wi-Fi connectivity through a laptop or Windows Mobile PDA device such as Pocket PC.

The controller shall incorporate a separate real-time clock backup power supply to maintain on-board clock settings in the event of a power failure. The controller shall store programmed settings and schedules in non-volatile memory. The controller shall default to the last settings on power up.

The controller shall have a programmable speed threshold that allows a user to adjust the “YOUR SPEED” trip point. Threshold adjustments shall be in 1 mph increments. Range is 1–99 mph. It shall provide a “blank out” display at a programmable maximum vehicle speed.

6.3.5.1. Speed Thresholds

There shall be a minimum of four programmable speed thresholds: minimum display speed, posted speed limit, excessive speed, and maximum display speed. No speed is displayed below the minimum display speed to limit non-vehicle signals. Posted speed limit is set at the posted speed limit on the roadway to alert drivers they are traveling over the speed limit. Excessive speed is set typically 5 to 10 mile per hour over the posted speed limit for additional attention. No speed or a maximum value is displayed above the maximum display speed to limit drivers racing the speed display.

6.3.5.2. Modes

The display shall have a selectable feature to set the numeric value for constant, blank, flash or stay at max value, when the detected speed is higher than the minimum display speed. An independent display mode shall be adjustable for each of the three speed thresholds above the minimum display speed.

6.3.6. Radar Unit

The radar unit shall measure the speed of approaching vehicles only and shall not display the speed of traffic traveling in the opposite direction. With multiple vehicles approaching, the displayed speed reading must be solid and not fluctuate based on other vehicles' speeds. The radar unit shall be impervious to moisture and factory set for the required application. The radar component shall be an internal, low power, K-band FCC part 15 certified, license-free unit.

6.3.7. Communications

A BlueTooth™ or WiFi wireless and RS-232 or USB hardwire connections to the controller shall be provided using a Windows programming unit. The Windows programming unit shall be a BlueTooth™ or WiFi-ready mini-laptop or similar device. The unit shall be provided with communications/interface software and a communication cable. The communication ports shall allow uploading and downloading of controller data. Data shall include firmware update, time of day, special event, master shutdown, peak speeds, vehicle counts, maintenance, defaults and mode operation data and reports. If removable flash memory is used for data storage the minimum size shall be 4 GB.

Any configuration or data access shall require a strong password. BlueTooth shall be v2.1 or higher and the default security settings shall be changed. WiFi shall utilize WPA security at a minimum. Serial RS-232 or USB ports shall have restricted physical access. A strong password shall consist of eight characters minimum utilizing both characters and symbols.

6.3.8. Power Source

The radar sign system shall be powered by a 12VDC 84Ah valve-regulated absorbed glass mat (VR-AGM) battery, minimum. The battery shall be charged by AC power, 120V or 240V and/or a PV panel. The battery shall power the sign for 7 days minimum without charging. The radar sign system shall have surge protection to withstand high repetition noise transients stated in Section 2.1.6 of NEMA Standard TS-2 (50).

6.3.8.1. Battery Charger

The battery charger shall be capable of utilizing 120VAC and 240VAC input. The battery charger shall fully recharge the installed battery(s) overnight. This would facilitate quick re-deployment of the sign to another location without use of the solar panels for recharging. The battery charger shall be sized to provide approximately 15% of the rated battery capacity (64).

6.3.8.2. Solar Charging

The PV system shall be sized to extend sign operation to 28 days in locations with an unobstructed view of the southern arc. The PV panel is pointed south at a fixed tilt of 41°. A minimum solar charging system shall consist of a 65 watt PV panel and a 4.7A 12 volt solar charge controller. The PV panel shall be sized to provide 21 days of power in January assuming two days per week of cloud cover i.e. 15 days of solar charging. During the approximately 8 hours of daylight in January expect 2 hours of maximum solar radiation. The solar charge controller shall be sized at 125% of the PV panel amperage rating and provides overcharge protection, improves charge quality and prevents battery discharge during low light conditions. Detailed design assumptions, conditions, and calculations are provided in Appendix F.

Standard practice is to protect a system's power source with a fuse or circuit breaker; in this case there are two power sources, the PV panel and the battery. Typically the PV panel fuse is located at the panel and sized at least 150% of the panel's short circuit current or 1.5 x 3.75 A = 5.6 A for the Kyocera panel. The battery fuse is located near the battery and sized at 150% of the maximum battery charging current, in this case the same 5.6 A. The standard size fuse would be 6 A.

6.3.9. Support Assembly

The display shall be mounted on foldable or collapsible supports with spring-lift strut assist or better. The deployed display support assembly shall be a see-through design to avoid obstructing motorists' view of workers or pedestrians.

6.3.10. Warranty

Warranties shall conform to Section 86-1.05, "Warranties, Guaranties and Instruction Sheet," of the Standard Specifications (58). The manufacturer shall provide a written warranty and support against defects in materials and workmanship at no cost to the State for a period of two (2) years from operational acceptance/activation. The manufacturer shall provide support to the State within twenty-four (24) hours of receipt of a request for information or assistance during the warranty coverage period. Sign replacement within the warranty period shall be provided within ten (10) working days after receipt of failed sign at no cost to the State. Warranty documentation shall be given to the Project Engineer before installation.

6.3.11. Options

6.3.11.1. Data Logging

A data logger shall record the peak speed with a month, day, year, hour, minute and second stamp in user-defined periods or bins. The data logger shall be capable of storing a minimum of 4 million data points. The logged data shall be downloadable through a serial cable, cellular modem or wireless connection to a PDA or laptop. The logged data shall be formatted such that the information can be easily imported into a Microsoft Excel-compatible spreadsheet for processing and analysis. The sign shall be capable of logging vehicle speeds when the numerical display is "blanked out."

6.3.11.2. Global Positioning System (GPS)

A GPS unit may be incorporated to allow the system to automatically adjust date and time settings and enable sign coordinates to be accessed remotely.

6.3.12. Compliance

A Certificate of Compliance from the manufacturer shall be provided by the contractor to the Engineer certifying that the sign and any optional equipment comply with the requirements of any specifications employed and is in conformance with Section 6-1.07, "Certificates of Compliance," of the Standard Specifications (58).

6.4. Sign Maintenance Considerations

The survey of California practitioners provided useful insights sign maintenance experiences. These experiences should be taken into account when considering various radar speed sign specifications, applications and deployments. None of the lessons learned presented here are intended to dissuade the consideration and/or acquisition of radar speed signage; rather, this information is provided so that a community or agency and its personnel are aware of issues that may be encountered when working with this type of signage.

Some practitioners indicated that their radar speed signage had low maintenance requirements, while others reported spending significant amounts of time on maintenance. These discrepancies appear to be primarily related to the particular equipment manufacturer. As such, the reader is encouraged to closely investigate not only manufacturer literature, but also consult with other practitioners regarding their maintenance experience with a manufacturer's equipment. Additionally, some devices are more user friendly in terms of programming and working with in general. The specifications set out in previous sections of this chapter are intended to address this issue.

Many practitioners cited the susceptibility of this type of signage to vandalism, both short-term and over time. This includes breaking the sign's LEDs, sign components and solar panels. Graffiti is another concern, as is theft of sign components (and in the case of one community, the entire sign). While it may not be surprising that radar speed signs would be a target for vandals, perhaps given their symbolic relation to law enforcement, the potential for vandalism should be considered in their deployment. While the specifications set forth in this chapter address some design aspects that can help deter vandalism, time and budget should be allotted to vandalism-related maintenance needs. Additionally, increased police patrols in the area of the signs should be pursued immediately following deployment, possibly tapering off over time.

Several practitioners noted that the signage and equipment required frequent cleaning. This was particularly true of deployments employing solar panels, which required cleaning in order to perform optimally. Signage maintenance also involved cleaning the speed panel display and replacement of LED bulbs. Again, the frequency of these tasks varied by deployment, but should be anticipated and budgeted for when considering the use of radar speed signs.

The presence of trees or similar obstructions may impact signage, particularly permanent installations, in two ways. First, tree branches may obstruct the light necessary for the solar panels to operate properly and require greater reliance on grid or battery power. Also, tree debris such as broken branches, sap, etc., may contribute to the need for frequent panel cleaning and repair. A second concern posed by the presence of tree branches and other visual clutter is the ability of motorists to see the sign. If motorists cannot see their speed posted, they will not be able to react in the manner desired and the effectiveness of the sign in reducing vehicle speeds would be minimized.

Finally, several practitioners noted that battery drain was a problem for solar systems when the solar panels did not produce enough power, either because of solar exposure problems or dirt. In such cases, the backup batteries were drained more quickly. Similarly, when batteries experienced heavy use (either as the primary or backup power source) they required more frequent replacement. As such, time and budget for battery replacement should be allotted when signs are deployed.

As each deployment is different in nature, it is difficult to develop a specific regimen for maintenance based on survey responses. However, there are some general items that should be planned for when radar speed signs are deployed. These include:

- Plan and budget for routine maintenance work and parts replacement.
- Plan and budget for occasional heavy maintenance needs.
- Avoid or minimize deployment in areas of excessive tree canopy cover when using solar power.
- Consider visibility of the sign to motorists, particularly in areas of visual clutter (significant signage, tree branches, etc.).
- Consider the potential for vandalism and address accordingly through increased police patrols or other measures.
- Consider the performance capabilities and maintenance needs of battery power, either as a primary or backup power source.

6.5. Summary

This chapter has provided physical and functional specifications for both permanent post-mounted radar speed signs (and portable post-mounted signs) as well as trailer-based radar speed signs. The intent of these specifications is to guide future purchases and deployments. These specifications are presented to inform the reader on what design aspects should be considered and incorporated into any future radar speed sign purchases their agency may be considering. Additionally, information regarding the maintenance requirements of radar speed signage was discussed. This information was based on the experiences described by practitioners in the survey discussed in a previous chapter.

7. CONCLUSIONS AND RECOMMENDATIONS

Radar speed signs have seen increased application in recent years in communities across the United States. The application of radar speed signs has typically been made in a haphazard, unscientific manner, usually involving subjective judgment and only rarely supported by engineering studies. The devices are typically placed where there is a perceived problem, yet decisions to place the devices are rarely accompanied by efforts to quantify or otherwise understand the problem itself, let alone the potential effectiveness of a radar speed sign in addressing it. The excessive use of signage to solve any speeding-related problem, real or perceived, could lead motorists to disregard the signage in the long term. Consequently, it was necessary to establish criteria regarding when and how radar speed signage should be deployed to address safety and speed issues effectively. The work presented in this report has established what situations warrant radar speed signs, whether they have been effective in similar applications, where such signs should be located (both setting and placement), and how they should be procured (specifications), operated and maintained. The following sections summarize the conclusions drawn from this work.

7.1. Conclusions

7.1.1. Past Research

Results of past research on radar speed sign deployments indicated that radar speed signs were used in a number of common applications, including work zones, school zones, residential and commercial areas, and speed transition zones (signal approaches, rural-to-urban transitions, curve approaches, etc.). The problems that radar speed signs were typically employed to address included excessive mean and 85th percentile speeds, safety concerns, traffic issues, posted speed compliance, pedestrian presence, and safety/speeding concerns in school zones, work zones, and residential and commercial areas. The research indicated that radar speed signs often achieved their objective of a reduction in speeds. Depending on the application and problem being addressed, changes in speeds ranged from small to significantly large. The long-term impact of such signage varied; in some cases it was reported to have a positive impact over time (e.g., many months), while in other cases radar speed signs were reported to lose effectiveness within weeks of their deployment. No rigorous statistical or even basic evaluations examined the impacts of radar speed signs on reducing speed-related crashes—a significant research void.

7.1.2. Synthesis of Practice

A review of national and state practices was conducted, from both a legal standpoint and from the perspective of the standard guidance document (MUTCD), to determine what information was available and what practices are currently employed specific to radar speed signs. This review found that agency documents that specifically discussed radar speed signs varied considerably in the information they provided. In some cases, such as the Federal MUTCD, the information provided was broad and covered the basics of radar speed signage (appropriate applications, sign colors, etc.). In other cases, individual states provided detailed information on a variety of sign use considerations, including their proper placement, number of signs to deploy in particular situations, etc. Finally, some states mentioned the use of radar speed signs in state statutes, but provided no formal engineering documentation regarding their application.

Based on the information reviewed, it was concluded that the provisions set forth in the California MUTCD would serve as an adequate foundation for the warrants developed in the project. As these guidelines were already in place, deviation from them was not feasible. While much of the basic guidance provided by other states was similar to that of California's MUTCD, the level of detail and specificity varied widely. As a result, it would be difficult to reconcile the practices and guidance employed elsewhere into one cohesive approach to radar speed sign warrants.

7.1.3. Practitioner Survey

A survey of California practitioners regarding the use of radar speed signage indicated that 59 of 63 respondents use or have used radar speed signs. Speed trailers and permanent signage were the two most typical deployments mentioned. School zones hosted the majority of permanent deployments, while residential, commercial and work zones were the most common locations for portable sign applications. The primary use of the signage was for speed control. In most cases, reference documents such as the MUTCD were not consulted in planning a deployment.

Respondents reported experiencing a number of maintenance issues, particularly issues related to vandalism, battery life and solar panel cleaning. Many practitioners were aware of or had conducted accuracy checks on the vehicle speeds being measured by radar, but no formal, statistical-type evaluations were pursued in any case. Similarly, most indicated that no formal evaluation of speed trends following deployment had been done. Finally, no evaluations of the impact of signage on safety had been made.

7.1.4. Warrants

The warrants for the use of radar speed signs in California were developed based on the literature review and practitioner survey. The first step in developing warrants was consideration of application locations. Based on the general language of the California MUTCD, radar speed signage is permissible anywhere when used in conjunction with existing speed limit signage or advisory speed signage. Next, purposes for their deployment were identified, including addressing excessive mean and 85th percentile speeds, encouraging compliance with posted speed limits; alerting drivers to the presence of pedestrians; addressing vehicle speed issues in school zones, work zones, and residential and commercial areas; and applications such as speed transitions zones, signalized intersection approaches, etc. This was followed by a consideration of the factors and characteristics associated with the historical applications of radar speed signs. These were identified through the literature review and practitioner survey as speeding and crash problems.

Once these various factors and characteristics were identified, objective criteria were developed that can be methodically applied in evaluating potential deployments. These criteria were developed based on the results of previous research that focused on the impact radar speed sign treatments had on vehicle speeds. These criteria were primarily related to changes in mean speeds and 85th percentile speeds observed in various studies following deployment. In the absence of any data regarding impact on speed-related crashes at a site, conservative criteria were developed for that area of interest. Based on the work completed to this point, two levels of guidance were developed: general guidance and location-specific guidance.

7.1.4.1. General Guidance

General guidance warrants apply to cases where a radar speed sign may be used to address excessive mean speed and 85th percentile speed issues, ADT levels, speed limit compliance issues, accident history, pedestrian presence, and existing posted speed limits. The warrants developed for this level of guidance included:

- **85th percentile speed –** A radar speed sign may be considered when the observed 85th percentile speeds at a site exceed the posted speed limit by 5 mph or more.
- **Mean speed –** A radar speed sign may be considered when the observed mean speeds at a site exceed the posted speed limit by 5 mph or more.
- **Average daily traffic (ADT) –** A radar speed sign may be considered when ADT exceeds 500 vehicles.
- **Accidents –** A radar speed sign may be considered at sites exhibiting a correctable speeding-related accident history within a recent time period.
- **Pedestrians –** A radar speed sign may be warranted at sites with a pedestrian-related accident history.
- **Posted speed limit –** A radar speed sign may be considered in conjunction with other warrants when the posted speed limit at a site is 25 mph or greater.

7.1.4.2. Location-Specific Guidance

Location-specific guidance applies to the use of radar speed signs in school and park zones, work zones, and general street locations such as transition zones, curve warning sign locations, and signal approaches. The warrants developed for this level of guidance included:

- Schools and parks
  - A radar speed sign may be considered for use within one-half (1/2) mile of a school zone or park, and
  - A radar speed sign may be considered when the posted speed limit in a school zone or park area is 15 mph or greater, and
  - A radar speed sign may be considered when the 85th percentile speeds in a school zone or park area exceed the posted speed limit by 5 mph or more, or
  - A radar speed sign may be considered when the observed mean speeds in a school zone or park area exceed the posted speed limit by 5 mph or more, or
  - A radar speed sign may be considered when ADT exceeds 500 vehicles, or
  - A radar speed sign may be considered to supplement a conditional speed limit already in place (e.g., a sign stating “Speed Limit 25 when Children Present”)
- Street conditions
  - Transition zones – A radar speed sign may be considered in conjunction with other warrants where a speed transition zone exists (high to low speed limits).
  - Curve warning – A radar speed sign may be considered in conjunction with other warrants where a curve speed warning advisory sign exists (high to low speed).

  - Signal approach – A radar speed sign may be considered in conjunction with other warrants for high-speed signalized intersection approaches where the speed limit exceeds 45 mph.
- Work zones
  - A radar speed sign may be considered when the posted speed limit in a work zone is 35 mph or greater, and
  - A radar speed sign may be considered when the observed mean speeds in a work zone exceed the posted speed limit by 10 mph or more.
  - A radar speed sign may be considered when the observed 85th percentile speeds in a work zone exceed the posted speed limit by 10 mph or more.
  - A radar speed sign may be considered in work zones with a history of speed-related accidents.

7.1.5. Specifications

In addition to developing warrants for the use of radar speed trailers, specifications were developed for such equipment to guide practitioners in future purchases and deployments. The specifications developed related to the physical and functional specifications for both permanent post-mounted radar speed signs (and portable post-mounted signs) as well as trailer-based radar speed signs. Major points of the general specifications shared between post-mounted and trailer-based radar speed signs included:

- Dimensions – shall not exceed 36” in width, 48” in height and 12” in depth.
- Numeric display – shall consist of two 7-segment amber LED numerals.
- LEDs – shall be Institute of Transportation Engineers (ITE) amber in color.
- Wavelength from 590 to 600 nanometers.
- Rated for a life of 100,000 hours or more of continuous illumination.
- Shall be 2,250 candela per square meter (cd/m^2) or higher per California test 606.
- Numerals shall be eighteen (18) inches tall.
- All sign system functions shall be controlled by a dedicated on-board removable solid-state computer.
- The numeric display range shall be 0 to 99 mph.
- Display shall be capable of showing the speed of an approaching vehicle and showing a “blank-out” display, which has no visible message.
- Display must be highly resistant to damage from thrown or launched projectiles.
- Display window shall be ¼” minimum thickness shatter-resistant polycarbonate.
- Display and/or electronics enclosure shall be ventilated NEMA 3R compliant, or better.
- The radar sign’s operational temperature shall be -30° to 60° Celsius (-22° to 140° Fahrenheit) at a minimum.
- Only brass and stainless steel tamper-proof fasteners shall be employed in sign fabrication.
- Sign exterior shall be powder coated with seaside environment quality materials and processes.
- Display shall be wind load rated at 100 mph when installed to the manufacturer’s specifications.

- The enclosure shall have a label with the manufacturer's name, model number, serial number, date of manufacture and the rated voltage, current, power and volt-amperes, if applicable, permanently attached to the unit.

Note that additional details specific to post-mounted and trailer-based signage were developed. These have been excluded in this summary for brevity, but are presented in detail in Chapter Six.

7.1.6. Maintenance Considerations

The survey of California practitioners provided useful insights into sign maintenance experiences. These included:

- Plan and budget for routine maintenance work and parts replacement.
- Plan and budget for occasional heavy maintenance needs.
- Avoid or minimize deployment in areas of excessive tree canopy cover when using solar power.
- Consider visibility of the sign to motorists, particularly in areas of visual clutter (significant signage, tree branches, etc.).
- Consider the potential for vandalism and address accordingly through increased police patrols or other measures.
- Consider the performance capabilities and maintenance needs of battery power, either as a primary or backup power source.

7.2. Recommendations

A number of recommendations have been drawn from the information and conclusions developed during this work. These recommendations are intended to guide the reader in the use of radar speed signage.

7.2.1. Warrants for Use

The primary recommendation of this work is to employ the developed warrants in a systematic manner. In other words, sign deployments should follow the warranted applications outlined in this report. To a large extent, the warrants presented cover a wide range of the deployment settings already pursued in California. Where the warrants likely differ from current practice is in the call for different thresholds to be met before deploying signage. For example, mean speeds should be measured at a site of interest and be observed to exceed posted limits by five miles per hour *before* a deployment is considered. Currently, 85^{th} percentile or mean speed measurement is likely not occurring; rather, a sign is deployed to address a resident complaint or a problem perceived by the public (or police or traffic engineers), but not confirmed. Employing the warrants developed in this work will lead to a more systematic approach to the use of radar speed signs and, potentially, greater acceptance of and compliance with posted speed limits by the driving public.

7.2.2. Specifications

Application of the specifications outlined in this report could serve as a de facto baseline for future radar speed sign purchases throughout California. The specifications represent a minimum that should be required by agencies when considering a radar speed sign purchase. They detail all aspects (electrical, dimensional, luminary, performance, etc.) of radar speed signs (and trailers for mobile units), providing purchasers who may not be familiar with such devices with specific parameters to meet in procurement. Applying these specifications would help in improving the uniformity and standardization of the equipment procured and deployments pursued by agencies.

7.2.3. Legal Aspects

An examination of state legal codes made it clear that procedures governing the use of radar speed signs are not typically addressed in statute. Rather, most states adopt the MUTCD guidelines (or a state-specific version). California is to be commended for directly addressing "Vehicle Speed Feedback Signs" in its edition of the MUTCD. Other states do not specifically reference such signage in their MUTCD documents. While guidance provided by the Federal MUTCD may be assumed to apply in such cases, it might be advisable for those states to consider addressing radar speed signs in any future modifications to this document to be adopted in their state.

7.3. Future Research

A recommendation for future research is the need to evaluate the safety impact of radar speed signage. No work was identified that examined the effectiveness of radar speed signs in reducing crashes, aside from that of the California Highway Patrol, which only looked at general trends. This is logical since the primary intention of such signs is to reduce speeds; consequently, examining the impacts of these signs on speeds has been the focus of all the literature identified. However, previous research reviewed during the course of this project indicated that radar speed signs have been deployed to address safety concerns in addition to speed-related problems. In instances where signage has been deployed to address a safety issue, evaluations of its impact on crashes are necessary. To date, no such evaluations have been performed. Consequently, one avenue of useful research would be to measure what, if any, impacts radar speed signs have on crashes, both in the short term and over time.

While the warrants for use developed as part of this project are based on factual findings regarding the effectiveness of radar speed signs, none of those findings were observed in California. That is, no formal evaluation of the effectiveness of radar speed signs in reducing speeds (mean, 85^{th} percentile, etc.) in current California deployments have been published. While it is likely that speed reductions from the use of radar speed signs match those of other jurisdictions, it would be of interest to confirm whether this is the case. Similarly, it would be of interest to determine the effectiveness of such signage in urban versus rural areas of the state, between different application settings, and whether drivers in different regions of the state respond differently to the signs.

Finally, no work reviewed during this project discussed the specifics of sign placement, such as distance from the roadway edge, the impacts of viewing angles, etc. In relation to this work, while the state of California, specifically Caltrans, has permitting requirements that must be met when placing items such as signs and trailers on the roadside on state-controlled routes, these may vary from those imposed by local authorities for locations off state routes. While it may be assumed that local entities employ the guidance developed at the state level, this may not always be the case. Consequently, further research is required to determine whether the guidance outlined at the state level (in California and other states) is optimal in relation to radar speed signage. Such research would determine whether placement distances and angles produce more significant speed-reduction results than other strategies. Such work could lead to the development of more specific physical placement guidance than that presented in this document, which is based on existing state guidance.

8. APPENDIX A: DETAILS AND RESULTS OF PAST RESEARCH

The following tables present the specifics related to the results of previous research presented in Chapter 2. Previous studies are grouped by the type of setting investigated, e.g., workzone, school zone, etc. Additionally, results are broken out by the type of deployment made—trailer-based, permanent sign, etc.

Work Zones

Trailer Based						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Pesti and McCoy	Rural 4-lane divided interstate	Nebraska	38000 (ADT)	55 mph	3 - 4 mph reduction	20 - 40% increase in vehicles complying w/ speed limit Long-term reductions in speeds over 5 weeks
McCoy, Bonneson and Kollbaum	Urban 4-lane divided interstate	South Dakota	9000 (AADT)	55 mph	4 to 5 mph reduction	Before - 74+% speeding After - reduced by 20 - 25%
Carlson, et.al	Rural 4 lane divided U.S highway Short term work zones (1-12 hours)	Texas	7000 (AADT)	55 mph	2 mph (cars) 3 mph (trucks)	Speeding before versus after: Cars - 5.5 - 7.0% reduction Trucks - 9.6 - 24.4% reduction
Teng, et al.	Interstate and principal arterial	Las Vegas, NV	n/a	45 mph (principal arterial) 55 mph (interstate)	8-9 mph reduction	Size of displayed messages and use of flashing showed significant impact on speeding likelihood and speed reduction
Saito and Bowie	Urban interstates (number of lanes varied)	Utah	n/a	55-65 mph	7 mph reduction	Display appeared to lose effectiveness after one week
Chitturi and Benekohal	Rural 4-lane divided interstate	Illinois	n/a	n/a	4.4 mph reduction (immediate) 6.7 mph reduction (3 weeks)	All speed reductions found to be statistically significant
Fountaine, et al.	Rural two and four lane short-term work zones	Texas	n/a	n/a	5 mph reduction	Reduced percent of vehicles exceeding speed limit

Changeable Message Sign-Radar Combination						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Garber and Srinivasan	Suburban interstates and primary highway	Virginia	n/a	45 mph (primary) 55 mph (interstates)	Interstate - 5 - 10 mph reduction Primary - 8 - 12 mph reduction	Speed reductions at all sites and exposure durations found to be statistically significant
Garber and Patel	Rural 4-lane divided interstate Three signs used at beginning, midpoint and end of the work zone. Employed messages rather than vehicle speeds	Virginia	8400 - 33000 (AADT)	45 - 55 mph	4 - 17 mph mean speed reduction between 1st and 2nd sign 1 - 3 mph mean speed reduction between 2nd and 3rd sign	6 - 11 mph reduction in 85% speeds between 1st and 2nd sign 2 - 3 mph reduction in 85% speeds between 2nd and 3rd sign
Wertjes	Rural 4-lane divided interstate	South Dakota	4560 (ADT)	55 mph	In advance of taper - 1.7 mph reduction At taper - 1.6 mph reduction End of taper - 0 mph reduction	85th percentile speeds reduced In advance of taper - 68.2 - 66.5 mph At taper - 63.5 - 61.9 mph End of taper - 59.3 - 59.4 mph
Wang, et al.	Rural, 2-lane highway	Georgia	n/a	45 mph	7 - 8 mph reduction	Speed variance decreased significantly following deployment Long term speed reductions between 1 and 3 mph observed
Sorrell, et al.	Rural, 2-lane highway and interstate	South Carolina	n/a	45 - 55 mph (two-lane) 45 mph (interstate)	7 - 9 mph reduction (interstate) 5 - 7 mph reduction (two-lane)	85th percentile speeds reduced 6 - 9 mph (interstate) 2 - 4 mph (two-lane)

Post-Mounted Sign						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Maze	Rural 4-lane divided interstate in advance of a crossover	Iowa	n/a	55 mph	3 mph reduction	85th percentile speeds reduced by 5 mph

School Zone

Trailer Based						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Casey and Lund	Urban 2-lane	Santa Barbara, CA	n/a	25 mph	Mean speeds fell between 1.5 and 5 mph	14% speed reduction when speeds exceeded limit by 10mph 7% speed reduction when speeds exceeded limit by 5mph
Permanent						
Lee et al.	Urban arterial	South Korea	n/a	20 mph	5 mph reduction (2 weeks) 3.5 mph reduction (12 months)	Before - 26.5% speeding After (two weeks) - 9.9% speeding After (12 months) - 5.5% speeding
Ullman and Rose	Unspecified 2-lane	Texas	n/a	35 mph	School zone - 9 mph (short term) and 9 mph (long term) Transition zone - 2-3 mph (short term) and 1 mph (long term)	Primary reduction observed in school zones 85th% speeds reduced 10 mph (short term) and 8 mph (long term)
Thompson, et al.	Suburban local roads	Maine	n/a	15 mph	2 to 4 mph reduction	Vehicles exceeding the speed limit fell by 4 to 20%, depending on site Over 70% of vehicles still exceeded the speed limit
Saito and Ash	Urban/suburban two and multi-lane roads	Utah	n/a	20 mph	1 to 3 mph reduction	85th percentile speeds reduced by 2 to 4 mph
KLS Engineering	Urban two and multi lane arterials	Washington D.C.	10000 - 30000 (ADT)	15 mph	1 to 7 mph reduction Some minor increases observed (1-3 mph)	Speed reductions found to be statistically signifcant in only 25% of cases
Garden Grove	Arterial streets	California	8000 - 29000 (ADT)	35 - 40 mph	Mean speeds not examined	85th percentile speeds reduced by 1.5 to 9.8 mph
Hallmark, et al.	Semi-rural two lane	Iowa	2343 (ADT)	25 mph	5.4 mph reduction after 3 months	85th percentile speeds reduced 7 mph (3 months)

No evaluations of portable post-mounted devices have been made to date.

Additional Locations (Residential, Commercial, Speed Transition Zones)

Trailer Based						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Casey and Lund	Urban residential, commercial and undeveloped 2- and 4-lane roadways	Santa Barbara, CA	200-1200 vph	30 - 45 mph	10% mean speed reduction alongside trailer and 7% downstream	Reductions brief; speeds rose once trailers removed
Bloch	Urban, residential 2-lane roads	Riverside, CA	800 - 2400 (veh/ln/day)	25 mph	6.1 mph reduction beside trailer 2.9 mph reduction downstream 0.6 mph reduction downstream following removal	Minimal changes in speeds one week following removal
Donnell and Cruzado	Transition zones on 2-lane highways	Pennsylvania	n/a	45 - 55 mph (initial) to 25 - 40 (transition)	4.6 - 7.9 mph reduction (1 week) Reductions measured downstream of signs similar	3.1 to 9.2 mph increase 1 week following removal
Permanent sign						
Study	**Application**	**Locale**	**Traffic**	**Speed Limit**	**Mean Speed Change**	**General Effectiveness**
Traffic Engineering Division	Urban, arterials, collectors and local roads	Orange County, CA	n/a	n/a	4 mph reduction on all roads	Statistically significant reductions in 85th percentile speeds observed No carryover effects observed
Ullman and Rose	Sharp horizontal curve Approach to signalized intersections	Texas	n/a	30-55 mph	Signal approach - 3 mph (short term) and 0-4 mph (long term) Curve - 2-3 mph (short term) and 0-2 mph (long term)	85th percentile speeds reduced 2-4 mph (short term) and 0 -4 mph (long term)
Sandberg, et al.	Speed transition zones (rural to urban)	Minnesota	4000 - 12000 (ADT)	45 - 55 mph (initial) to 30 - 45 (transition)	1 week - 6 - 7 mph reduction 2 months - 3 - 8 mph reduction 7 months - 3 - 7 mph reduction 1 year - 6 - 8 mph reduction	85th percentile speeds 1 week - 6 - 8 mph reduction 2 months - 5 - 11 mph reduction 7 months - 5 - 7 mph reduction 1 year - 5 - 9 mph reduction
Hallmark, et al.	Transition zones on two lane highways	Iowa	300 - 2300 (ADT)	55 mph (initial) to 25 (transition)	1 month - 1 mph reduction 3 months - 0 mph reduction 9 months - 1 to 5.2 mph reduction 1 year - 1 to 3.4 mph reduction	85th percentile speeds: 1 month - 2 mph reduction 3 months - 1 mph reduction 9 months - 1 to 4 mph reduction 1 year - 2 to 3 mph reduction
Chang, et al.	Collector and arterial streets	Washington	2700 - 4900 (ADT)	25 mph	1.19 and 2.21 mph reduction	Only one site found to have statistically significant speed reduction
Tribbett, et al.	Rural Interstate	California	7650-9300 (AADT)	50 - 60 mph	1 to 5 mph reduction	Results were mixed, as some sites saw significant speed reductions, while others saw increased speeds

9. APPENDIX B: STATE GUIDANCE

The following sections provide more detailed information regarding the specific radar speed sign guidance employed by various states.

Arizona

Information that pertains to the use of such signage in school zones:

Standard: The School Speed Limit assembly shall be either a fixed-message sign assembly or a changeable message sign.

The fixed-message School Speed Limit assembly shall consist of a top plaque (S4-3) with the legend SCHOOL, a Speed Limit (R2-1) sign, and a bottom plaque (S4-1, S4-2, S4-4, or S4-6) indicating the specific periods of the day and/or days of the week that the special school speed limit is in effect (see Figure 7B-1).

Option: Changeable message signs (see Sections 2A.07 and 6F.55) may be used to inform drivers of the special school speed limit. If the sign is internally illuminated, it may have a white legend on a black background. Changeable message signs with flashing beacons may be used for the more critical situations, where greater emphasis of the special school speed limit is needed.

Guidance: Even though it might not always be practical because of special features to make changeable message signs conform in all respects to the accepted standards, during the periods that the school speed limit is in effect, their basic shape, message, legend layout, and colors should conform to the standards for fixed-message signs.

A confirmation beacon or device to indicate that the speed limit message is in operation should be considered for inclusion on the back of the changeable message sign.

Option: Fluorescent yellow-green pixels may be used when school-related messages are shown on a changeable message sign.

Changeable message signs may use blank-out messages or other methods in order to display the school speed limit only during the periods it applies.

Changeable message signs that display the speed of approaching drivers (see Section 2B.13) may be used in a school speed limit zone.

Note that these references are to sections of the 2003 Federal MUTCD, which presents general use of radar speed signs.

Texas

Section 2B.13 related to speed limit signing provides an option and guidance for radar speed signage:

Option: A changeable message sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit sign.

Guidance: If a changeable message sign displaying approach speeds is installed, the legend YOUR SPEED XX MPH or such similar legend should be shown. The color of the changeable message legend should be a yellow legend on a black background or the reverse of these colors.

Minnesota

The Minnesota DOT technical memorandum to provide guidance on radar speed signs states the following:

Dynamic Speed Display (DSD) signs installed in permanent speed zones should operate 24 hours a day 7 days a week.

DSD signs installed on temporary speed zones should operate for the time period that the speed zone is in effect (ex. school zones, work zones, etc.).

Within work zones**,** it is highly recommended that DSD signs are used sparingly and strategically to avoid over usage of the devices.

Typically, only one DSD sign should be used (per direction of traffic flow) within a work zone and should be placed before an occupied work area. In stationary work zones, the DSD sign location shall be reviewed daily as work progresses through the work space for optimal effectiveness.

DSD signs are typically used adjacent to an appropriate warning sign/advisory speed plaque.

The DSD sign and worker ahead/advisory speed plaques are only allowed when workers are present and adjacent to moving traffic. These signs should be located approximately the distance "A" ahead of the workers. "A" is the typical distance between advance warning signs as shown in the current MN MUTCD Table 6C-1. As the workers proceed downstream, the signs should also move such that they are not greater than 760 meters (2500 feet) from the workers and not less than 80 meters (250 feet) to the workers. These distances should be adjusted where horizontal or vertical curves restrict the sight distance to the workers.

The DSD sign may be used with a warning sign / advisory speed plaque for hazardous conditions within a work zone. It is recommended that a DSD sign only be utilized where it is most imperative for the motorist to adjust speed to safely navigate through hazards such as near bypasses, drop-offs, narrow lanes, grade separations and pavement repair. When used, the DSD and adjacent warning sign / advisory speed plaque should be located approximately the distance "A" ahead of the hazard. "A" is the typical distance between advance warning signs as shown in the current MN MUTCD Table 6C-1.

DSD signs installed by local agencies on Trunk Highways.

The DSD sign shall be installed by permit only through Mn/DOT District Offices and reviewed annually. All costs related to installation shall be paid by the requesting agency.

The usage of DSD signs is limited to one DSD sign used per approach of speed transition zones such as at city limits, school zones or other large speed reduction transitions.

A request to relocate a sign shall be approved by Mn/DOT. The cost to relocate the sign shall be paid by the requesting agency (34).

Missouri

The Missouri DOT Engineering Policy Guide states:

Radar Speed Advisory Assembly: These devices contain an active display that indicates the speed of each vehicle as it passes the sign. These devices are recommended on divided highways with lane closures, multilane urban or rural resurfacing projects over 5 miles and bridge rehabilitation projects with lane restrictions lasting 30 days or more. These devices shall not be used on routes with a posted speed prior to construction less than 50 mph. Other conditions may warrant the use of this device.

Tennessee

The Tennessee DOT radar speed sign guidance provided by the Work Zone Safety and Mobility Manual states:

Dynamic speed message sign: Either fixed-mounted on the ground or on a portable trailer, this device may be used to enforce reductions of speed limits. Typically these signs are positioned at the beginning of the work zone and also may be located within the work zone. The Transportation management Plan may recommend the use and placement of these to supplement police enforcement measures.

Kentucky

Kentucky information on radar speed signs is provided through the state's driver safety manual. The manual notes that signage is used:

To promote safety for the Commonwealth, the Division of Driver Safety uses Speed Monitoring Awareness Radar Trailers (SMART) on high-crash corridors, work zones, and other problem roadways, as well as in highway safety school programs, parades, festivals, and fairs.

Indiana

The Indiana DOT information specific to the use of radar speed signs applies to general applications as well as school zones, stating:

Section 2B.13 Speed Limit Sign (R2-1)

A changeable message sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit sign.

Guidance: If a changeable message sign displaying approach speeds is installed, the legend YOUR SPEED XX km/h (MPH) or such similar legend should be shown. The color of the changeable message legend should be a yellow legend on a black background or the reverse of these colors.

Support: Advisory Speed signs are discussed in Sections 2C.36 and 2C.46 and Temporary Traffic Control Zone Speed signs are discussed in Part 6.

Section 7B.11 School Speed Limit Assembly (S4-1, S4-2, S4-3, S4-4, S4-6, S5-1)

Standard: The School Speed Limit assembly shall be either a fixed-message sign assembly or a changeable message sign.

Guidance: Changeable message signs that display the speed of approaching drivers (see Section 2B.13) may be used in a school speed limit zone.

Michigan

The Michigan MUTCD radar speed sign section states:

Section 2B.13 Speed Limit Sign (R2-1)

Guidance: A changeable message sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit sign.

If a changeable message sign displaying approach speeds is installed, the legend YOUR SPEED XX km/h (MPH) or such similar legend should be shown. The color of the changeable message legend should be a yellow legend on a black background or the reverse of these colors.

Support: Advisory Speed signs are discussed in Sections 2C.36 and 2C.46 and Temporary Traffic Control Zone Speed signs are discussed in Part 6

Option: Changeable message signs may use blank-out messages or other methods in order to display the school speed limit only during the periods it applies.

Changeable message signs that display the speed of approaching drivers (see Section 2B.13) may be used in a school speed limit zone.

Ohio

The Ohio DOT provides the following information on radar speed signs:

Section 2B.13 Speed Limit Signs (R2-1, R2-H2b, R2-H2c)

Option: A changeable message sign that displays to approaching drivers the speed at which they are traveling may be installed in conjunction with a Speed Limit sign.

Guidance: If a changeable message sign displaying approach speeds is installed, the legend YOUR SPEED XX MPH or such similar legend should be shown. The color of the changeable message legend should be a yellow legend on a black background or the reverse of these colors.

Support: Information about the speed zoning process and copies of the related forms are also available by contacting the ODOT District Office. Advisory Speed signs are discussed in Sections 2C.36 and 2C.46 and Temporary Traffic Control Zone Speed signs are discussed in Part 6.

Option: Changeable message signs that display the speed of approaching drivers (see Section 2B.13) may be used in a school speed limit zone.

Maryland

The Maryland State Highway Commission provides extensive deployment guidelines in its document "Use of Speed Display Trailers in Work Zones." This guidance states:

The speed display trailer should be used in work zones where speeding is expected to be or has been shown to be a problem.

Speed display trailers may be used in both urban and rural areas; however, its use in urban environments is discouraged due to the smaller display.

Speed display trailers should not be used on highways with three or more lanes in one direction. In these cases, Portable Changeable Message Signs (PCMS) with Speed Display feature are recommended.

Preferably, speed display trailers should not be used over an extended period of time (i.e., for more than two weeks), particularly in locations with high commuter traffic volume.

However, if the display is going to be active for several weeks, periodic police enforcement should be arranged to maintain its effectiveness.

The speed display trailer should be placed upstream of the work zone location (e.g., workers and equipment very near the traffic stream, hidden or unobvious work zone conditions, locations where an engineering study has indicated that drivers tend to increase speed).

The mounting height, lateral offset, and orientation of the speed display trailer shall conform to applicable guidelines from MUTCD sections 2A.18, 2A.19, and 2A.20.

The speed display trailer should be delineated/protected with traffic control devices as shown in SHA's temporary traffic control typical applications.

To maintain speed reductions throughout the work zone, more than one speed display trailer should be used in work zones longer than one mile.

The speed display trailer should be sited and aligned to provide maximum legibility.

If two speed display trailers are used, they should be placed on the same side of the roadway and be separated by at least 1,000 ft. Placement on both sides of the roadway at the same location may cause driver distraction and conflicting messages.

Each time the SDT is set up, the radar should be checked and adjusted (if necessary) to ensure accuracy.

The radar should be aimed to measure the speeds of vehicles traveling on the fastest moving lane, at no more than 10 seconds of distance upstream of the radar location.

The speed display should be activated only when an approaching vehicle is detected traveling at 3 mph or more over the speed limit. If no vehicles are approaching, the display should be blank.

On high-speed facilities (i.e., roadways where the posted speed limit is 50 mph or greater) the speeds of vehicles traveling more than 25 mph over the speed limit should not be displayed. This measure is intended to discourage drivers from seeing how fast they can get the speed display trailer to read.

The display should be visible from ½ mile under both day and night conditions.

The sign should be legible from a minimum distance of 650 feet.

The text size of the LED speed display digits should be 18 inches for standard applications, and 24 inches for freeways/expressways.

Pennsylvania

Pennsylvania provides radar speed sign guidance in the document "Official Traffic Control Devices," Pennsylvania's supplement to the MUTCD:

212.419 Special controls in work zones

(h) Speed display sign: In Interstate highway work zones with a project cost exceeding $300,000, a speed display sign shall be installed on each mainline approach zone to inform motorists of their speed.

(1) The speed display sign must display the motorist's speed in miles per hour in numerals at least 18 inches in height.

(2) As an alternative, a portable changeable message sign (PCMS) may be equipped with radar and programmed to display vehicle speeds.

(3) PCMSs may also flash appropriate messages such as "YOU ARE SPEEDING" or "SLOW DOWN." The signs shall be placed ½ to 1 mile in advance of the physical work zone.

Delaware

The Delaware state safety programs engineer developed a guidance memorandum discussing the use of radar speed signs, including:

1) An entity wanting to place a Portable Speed Display device within State of Delaware rights-of-way shall fill out an approval form. The approval form may be submitted by email as directed and shall be submitted no later than 72 hours in advance of device placement.

2) Prior to placement of a Portable Speed Display device, the contractor or municipal agency shall notify DelDOT's Transportation management Center (TMC) 24 hours in advance of placement. The phone number of the TMC is (302) 659-4600. The contractor or municipal agency placing the device shall provide the exact location at which the device will be placed, the duration the device will be used, the license plate number of the device (if the trailer version is being used) being placed and a name and 24/7 phone number for a contact person that can be reached in case of emergency or in case of removal of the device by DelDOT forces. Unapproved devices located in the rights-of-way of the State shall be removed immediately.

3) In accordance with Section 6F.55 of the Delaware Manual on Uniform Traffic Control Devices (Delaware MUTCD), six (6) channelizing devices (drums or cones) shall be provided to close the shoulder in advance of each Portable Speed Display trailer located within the shoulder during daytime. When the Portable Speed Display device will be on site at night, drums shall be utilized and one (1) amber Type B light shall be provided on each of the first two drums. If all drums meet the new sheeting requirements, lights shall not be utilized (See Section 6F.62 of the Delaware MUTCD for drum sheeting requirements).

4) Drums or cones being utilized shall conform to Section 6F.62 of the Delaware MUTCD.

5) Portable Speed Display devices shall not be placed within the travel lane on any roadway.

6) If a shoulder does not exist on the subject roadway, the Portable Speed Display device shall be placed outside of the travel lane, behind the curb or in another location that presents the least practicable obstruction to the motoring public.

7) Portable Speed Display devices shall be placed so as to minimize the potential of being struck by an errant vehicle.

8) Portable Speed Display devices shall not be placed in a manner in which they restrict sight distance of block other regulatory, warning or guide signage.

9) Portable Speed Display devices shall not block existing driveway entrances or intersections.

10) If a sign panel only device is used, the device shall be mounted on a separate mounting system and the mounting system shall be of a breakaway construction. The contractor or municipal agency installing the device shall be responsible for contacting Miss Utility for underground utility locations.

11) Sign panel only devices shall not be attached to any DelDOT facility such as a light pole, pedestrian signal pole, traffic signal pole, or other sign post, etc. by any entity other than DelDOT. Signs attached to these appurtenances shall be removed by DelDOT forces immediately.

12) If a static speed limit sign is placed on the Portable Speed Display device, the speed limit sign shall match the existing speed limit on the subject roadway. The speed limit sign shall be in accordance with Section 2B.13 of the Delaware MUTCD.

New York

The New York DOT guidance related to radar speed signs for work zone applications states:

Portable Variable Message Signs

Portable Variable Message Signs (PVMS) with built-in radar detectors can be used to alert drivers that they are exceeding the speed limit with the message:

YOUR SPEED IS XX MPH

SLOW DOWN YOU ARE SPEEDING

PVMS equipped with trigger panels should be programmed using a “Trigger Speed” of 10 mph above a posted speed limit of 45 mph or higher and a “Trigger Speed” of 5 mph above a posted speed limit of 30 mph to 40 mph. PVMS should be utilized to alert drivers that they are exceeding the speed limit. PVMS should be de-activated during periods of traffic congestion, and regularly moved to enhance effectiveness. Overuse may desensitize the motoring public to their use and reduce their effectiveness.

Speed Display Trailers

Speed Display Trailers with built-in radar detectors can be used to alert drivers that they are exceeding the speed limit by displaying approaching vehicle speeds. Speed Display Trailers are to be supplied, positioned, maintained, and removed by the Department. Speed Display Trailers should be de-activated during periods of traffic congestion, and regularly moved to enhance effectiveness.

Vermont

The State of Vermont Agency of Transportation provides conditions where radar speed signs should be used, as well as the technical requirements associated with them:

Conditions for Use: When requested, Radar Speed Feedback Signs (RSFS) will be considered for use on the State Highway System where all of the following conditions exist:

The 85^{th} percentile speed, as determined by a speed study, exceeds the posted speed limit by at least 3 MPH during the time period of concern (e.g. the ½ hour before to ½ hour after a school arrival/dismissal time or other peak traffic period).

Where a speed transition exists (e.g. going from a 40 MPH posted speed to a 30 MPH posted speed or in a School Speed Zone).

Where the posted speed is 35 MPH or less.

Installation may be considered for locations where crash data can be clearly linked to excessive speed.

Technical Requirements: RSFS must meet the following specifications and documentation to that effect must be supplied to the VTrans Utilities and Permits Chief as outlined in Section H

1. Installation shall be in conjunction with a Speed Limit sign (standard or school speed zone).

2. Installation is restricted to one RSFS in each direction for the transition area being addressed.

3. The RSFS shall include the legend "YOUR SPEED xx MPH" or similar legend. The color of the changeable message legend shall be a yellow legend on a black background or the reverse of these colors.

4. The changeable display shall be programmed to go blank/no display when the vehicle speed exceeds 15 MPH over the posted speed.

5. When activated, the RSFS display shall give drivers immediate feedback on their individual driving speed when the posted speed is exceeded without animation, rapid flashing, or other dynamic elements.

6. When installed in association with school speed zones, the RSFS shall operate only when the school speed zone is in effect. (Generally, the RSFS will operate only on days that schools are in session, for thirty minutes before and fifteen minutes after the time in which the school day begins; and fifteen minutes before and thirty minutes after the time in which the school day ends). Use of RSFS in conjunction with school speed zones "when children are present" is not allowed.

7. Information shall be supplied that documents that the RSFS and sign support assembly and installation meet the requirements for crash-worthiness as defined in the National Cooperative Highway Research Program (NCHRP) Report 350.

8. The installation shall **not** interfere with the visibility and general effectiveness of any other signs in the area.

9. All elements of the RSFS shall conform to the guidance and standards as outlined in the latest edition of the MUTCD.

10. Identification and contact information for the municipality in which it is installed shall be displayed on the case of the RSFS.

Massachusetts

MassDOT does not provide specific guidance on radar speed signs, but the Executive Office of Public Safety and Security provides basic information:

> Speed feedback signs are most effective at the first point of motorist visibility and for a short distance past the site. Place speed monitors at the beginning of your selected enforcement site to maximize speed reduction throughout the enforcement area.
>
> Displaying a speed monitor over a short-term period seems to be more effective than using it for a long-term period. Drivers begin to ignore the monitor when its placement seems permanent. We suggest that you use the monitor in random locations, on random days and times.
>
> Speed feedback signs are more effective with associated enforcement efforts. Using them without enforcement is not recommended.

10. APPENDIX C: SURVEY FORM AND USER RESPONSES

Survey Form

The use of radar speed signs in California communities has increased in recent years. These devices, which measure (typically by radar) and display vehicle speeds, may take on a mobile (trailer-based) form or a permanent pole/post-mounted digital display board. Typically, the application of radar speed signs has taken on a randomized approach, with signs being deployed wherever they are perceived useful. The excessive use of signage in this manner could potentially lead motorists to disregard it long-term. Consequently, the California Department of Transportation (Caltrans) District 2 is investigating the development of criteria regarding when/how such signage can be deployed and operated to address safety and speed issues effectively.

As a part of this work, the following survey has been developed to obtain information related to the use of radar speed signage in local communities. Please take a few moments to complete the questions below, keeping in mind the more specific information that is provided, the more useful it will be to the end result of this work. Upon completion, the results of this effort will be available to all for general use via Caltrans' Division of Research and Innovation.

This survey should take between 5 to 10 minutes. If you have any questions, please contact David Veneziano of the Western Transportation Institute at: david.veneziano@coe.montana.edu

Thank you for your time and participation!

Below are images of radar speed signs for your reference.

Image source: http://www.trafficlogix.com/radar-speed-signs.asp

Q1 Contact information (all information will remain confidential)

First Name

Last Name

Position

Agency/Community

Address

City

Telephone

Email

Q2 Would you like to receive the results of this research by email when the effort has concluded?

- Yes
- No

Q3 Are radar speed signs of any form (mobile-trailer, fixed signage, other) employed in your community (if no, please proceed to the end of the survey)?

- Yes
- No

Q4 Which of the following devices does your community/agency use (select all that apply):

- Fixed radar speed sign (mounted permanently as a speed limit sign)
- Radar speed trailer
- Portable radar speed sign (removable from sign pole, not fixed on a trailer)
- Changeable message sign equipped with radar

Other (please describe)

Q5 Where is such signage employed (select all that apply)?

☐ School zones

☐ Work/construction zones

☐ Residential neighborhoods

☐ Business district

Other (please describe)

Q6 Are these deployments permanent or portable?

	Permanent	Portable
School zones	Are these deployments permanent or portable? School zones Permanent	Portable
Work/construction zones	Work/construction zones Permanent	Portable
Residential neighborhoods	Residential neighborhoods Permanent	Portable
Business district	Business district Permanent	Portable
Other	Other Permanent	Portable

Q7 When are such devices used in your community – i.e. speeding issues, safety issues, etc. (please describe)?

Q8 Is any formal guidance referenced when deploying such devices (legal code, engineering guidance document, etc.)?

☐ Yes

☐ No

If yes, what document/source?

Q9 If your community is employing radar speed signage, what equipment (manufacturer and model) is being used? (Note: if more than one type/model is being used, please provide information on all devices if possible).

Q10 What power systems are employed as part of the signage (select all that apply)?

	Connected to Grid	Battery Power (backup system)	Solar Power	Generator
Fixed radar speed sign	☐ What power systems are employed as part of the signage (select all that apply)? Fixed radar speed sign Connected to Grid	☐ Battery Power (backup system)	☐ Solar Power	☐ Generator
Radar speed trailer	☐ Radar speed trailer Connected to Grid	☐ Battery Power (backup system)	☐ Solar Power	☐ Generator
Portable radar speed sign	☐ Portable radar speed sign Connected to Grid	☐ Battery Power (backup system)	☐ Solar Power	☐ Generator
Changeable message sign	☐ Changeable message sign	☐ Battery Power (backup system)	☐ Solar Power	☐ Generator

	Connected to Grid	Battery Power (backup system)	Solar Power	Generator
	Connected to Grid			
Other	☐ Other Connected to Grid	☐ Battery Power (backup system)	☐ Solar Power	☐ Generator

Q11 Does your agency have any specific functional/electrical specifications for such devices? If so, please list that information below.

Q12 Do you have any information related to maintenance of the signage that is of interest? For example, what activities are required short and long term, does the device require a high or low amount of maintenance, and lessons that have been learned over the course of deployment?

Q13 Do you perceive the speed measurements by the sign to be accurate?

○ Yes

○ No

Has any formal validation been made? If yes, what have the results found?

Q14 Has your community conducted any evaluation of the impacts radar speed signage has on speeds (ex. reductions of mean speeds, 85th percentile speeds, etc.)?

◉ Yes

○ No

If yes, what have the results found?

Q15 Has your community conducted any evaluation of the impacts radar speed signage has on safety/crashes (ex. reductions in crashes, etc.)?

☐ Yes

☐ No

If yes, what have the results found?

Q16 Do you have any additional radar speed sign information you would like to share?

Q17 If you know of any other contact that may have information of interest for this survey, please provide their information below (or forward them the link to this survey).

Q18 May we contact you if additional information is needed?

☐ Yes

☐ No

Thank you for your time and participation!

User Responses to Questions

Applications

1. To enforce a 25 MPH speed limit in a school zone during morning and afternoon hours. To enforce a 40 MPH speed limit for a downhill portion of a street in a residential setting.

2. speeding issues and safety issues

3. These devices are generally used when a resident has speeding concerns along a particular stretch of roadway.

4. The devices were placed for speeding and/or safety issues. We have placed on a 2-lane conventional highway with a number of head-on collisions which excessive speed may be a

factor. We also have installed such devices in residential areas where the residents complained about excessive speed.

5. safety and speeding

6. in School zones on collector and arterial roadways

7. Predominantly for speeding issues. The mobile unit has been used in locations where there is a perception of a speeding issue as an informative tool.

8. Speeding issues, at locations with high accident occurrence

9. Speeding issues, special events, and complaint-related

10. In school zones we use them where the speed limit is higher than 25 mph and the signs operate at the beginning and end of school days. The portable radar sign is used in residential areas at the request of residents (speeding issues). Length of use is about 7 days at each location. Business district we installed sign for one direction where the approach speed is 50 mph going down to 25 mph and little enforcement.

11. To help with speeding and increase safety within our school zones. these are most effective in our rural areas where the speed limits approaching the schools is generally 55 MPH.

12. In response to citizen complaints regarding speeding.

13. Speeding issue

14. Response to speed complaints

15. Motorist information

16. Speeding issues for permanent installation. Safety issues for work zones on major routes.

17. Fixed units are located adjacent to mid-block, unprotected school crossings; mobile units are used in advance of construction zones and in response to citizen speeding complaints

18. They are placed on our major roadways periodically, plus when we get a complaint about speeding.

19. Speeding

20. Speeding and Safety issues.

21. trailer-routine and deployed following complaints; pole mounted are part of arterial traffic calming program City wide

22. mostly related to speeding and safety issues raised by the public citizen.

23. Generally following complaints of speeding from the community. The trailer is used to educate drivers as well as gather information for staff to evaluate conditions.

24. Speed Issues, Traffic Calming

25. Mostly used in areas where citizens are complaining of speeders

26. Typically when a speeding concern is brought to our attention by a resident

27. All portable

28. Speeding

29. The radar trailers are deployed when complaints about speeding vehicles are received Wed,

30. Speeding and shortcutting concerns

31. Safety is the primary criteria; accident rates that are above average are a criteria. Areas with lots of tourists and visual competition for existing speed limit signs is another potential reason.

32. Speeding in School Zones and Downtown District

33. Perceived speeding issues, high pedestrian volume locations, citizen demand for traffic calming strategies

34. When requested, or where we receive speeding complaints by local residents in residential areas. In select school zones.

35. Addressing Community complaints, at the beginning of school years, when addressing changes in the roadway.

36. Trailer mounted units are deployed by the Police Department on a complaint basis. We have just started using permanent units. Currently they are used only in areas with known speed issues.

37. speeding issues

38. Speeding issues. Addressing high collision rate locations related to excessive speed.

39. Speeding and safety issues

40. Speed trailer is used for motorist feedback to address speed-related safety issues but it is not used directly for speed enforcement.

41. Resident Complaints

42. Our variable message sign with radar is deployed when complaints of excessive vehicle speeds are received. The trailer mounted radar is used by our Police Department to also address residents' complaints of excessive vehicles speeds, but mainly on residential streets.

43. speeding issues in a high school zone and residential neighborhoods

44. High accident areas, request by citizens regarding complaints of speeding drivers

45. Based upon community complaints and collision rates

46. We primarily use them in school zones, but have used radar speed trailers in residential areas along collectors where speeding is a problem.

47. All of our fixed signs are in school zones to address speeding issues. Our portable trailer sign is deployed at locations where speeding has been reported and is used as an educational tool.

48. Safety issues relating to speeding and in neighborhoods/schools as a speed reminder.

49. These devices are usually employed upon complaints by residents and schools.

50. Speeding issues which relate to safety.

51. SPEEDING ISSUES AND BASED ON RESIDENT REQUEST, PLANNING & TRANSPORTATION COMMISSION REQUEST

52. Speeding issues; sometimes when Police staff resources are limited, deploying the trailer is more efficient

53. Speeding issues; safety issues, pedestrian crossing, roundabout, near schools, near park, construction zone, sloppy roadway,

54. Chronic speeding areas, particularly associated with accidents that can be attributed to speed issues.

55. SPEEDING

56. speeding complaints

57. Address and verify citizen concerns about speeding.

58. Typically safety issues

Manufacturer Information

1. VSC-1820 (solar) at our residential setting. 3M Driver Feedback Sign 75-0301-6570-0 (connected to grid) at our school location.

2. Speed Check

3. Fixed radar speed sign - 3M Driver Feedback Signs (24 VDC with Solar/Battery) Radar speed trailer - U.S. Traffic Corporation (National Signal) PVSD Sunray 115R-CA 20 Deg LED 7 Segment Radar Trailers

4. Our projects only specify the specifications and up to the contractor to provide an equipment that would meet the specifications.

5. don't know

6. Fortel

7. 3m products, portable radar trailer

8. Don't know

9. 3M Driver Feedback Sign.

10. National Signal, 3M, Traffic Solutions

11. 15" Speed Sentry, Model 4000177, Wattco Equipment, Inc.

12. unknown

13. Radarsign

14. Kustom Signals INC, Smart models 1 trailer

15. ?

16. Permanent: SpeedCheck

17. TAPCO 3158-1

18. All Traffic Solutions - Speed Sentry

19. Unknown

20. Unknown

21. Trailer - owned by Police Dept pole mounted - Fortel VCalm, VMS-C model

22. (1) SPEEDCHECK Fixed-Mounted VSC-1520F Model (15" High Display Characters)

(2) VATCS - Speed Feedback Display – SFD (3) K&K Systems, Inc. - 2000RPM18-pole mounted radar speed monitor, 18' LED Display

23. PERMANENT - RADARSIGN MODEL TC-500

24. unavailable

25. Radarsign TC 500 & TC 1000

26. Kustom Signals RADAR trailer

27. MPH

28. One radar trailer-Kustom Signals (15 year old) One radar trailer-Decatur Electronics on-site 400 (3 years old)

29. Fortell V-Calm

30. Fortel and IDL

31. VCalm CMS Phase 4, IDC speed sign, RU2 radar trailer

32. 3M Fortel Speed Display Company

33. Information Display Veritext

34. RU2 model numbers 275 & 350 Speed Check model number 1520f-v50

35. Fortel VSC 1520

36. Don't know

37. Fortel VCalm

38. We've used the fixed/portable signs on a pole are made by 3M Company and the trailer is made by US Traffic Supply

39. Please contact CSO Aubrey Dietrich at (949) 283-0912. She will have this information that you need.

40. Unknown make and model

41. RU2, Speed Check, and Fortel

42. We have five solar powered SpeedCheck signs and one hard wired Fortel sign. We also have several more to be installed as part of a safe routes to school grant.

43. Don't know.

44. ForTel - VCalm-VMS-Solar (both portable and trailer mounted) - Have 8 portable and one trailer

45. Fortel VCalm VMS Information Display SpeedCheck 1520

46. Fortel V-Calm (solar)

47. SpeedCheck / Information Display Company 10950 SW 5th Street, Suite 330 Beaverton OR 97005 Model VSC 1820 (Large display)

48. Don't know.

11. APPENDIX D: SPOT SPEED STUDY OVERVIEW

The information presented in this appendix provides an overview of how to conduct a spot speed study. This information is provided for personnel and/or agencies who are considering the use of a radar speed sign but need to confirm whether an existing speed problem exists. The authors note that engineering practitioners are familiar with spot speed studies; however, non-engineering personnel or agencies (such as police) may not be familiar with the technique. It is for that reason that this appendix is provided.

Background

Spot speed studies are used for a number of different applications, including the monitoring of speed trends (establishing current conditions) and measuring the effectiveness of operational or control changes (determining whether speeds have fallen following radar speed sign use). Spot speed study data collection is performed either directly or indirectly. Direct data collection uses technologies such as radar or lidar or stop watches (timing a vehicle between two points) to measure the speed of passing vehicles. Indirect data collection processes typically use equipment such as pneumatic tube counters to determine the time it takes a vehicle to pass between two points and, through subsequent calculations, the traveling speed. Both approaches provide the same information (speeds); the selection of the approach that will be employed depends on factors such as available budget, available equipment, and so forth.

Before a method for speed collection can be selected, however, the problem at hand must be determined. In determining whether a radar speed sign should be employed, one must find out whether a speeding problem exists. This may be established by measuring mean speeds, the percentage of observed vehicles exceeding the posted speed, or the number of vehicles exceeding the 85^{th} percentile speed. Any of the data collection techniques mentioned previously may be employed for this purpose.

In determining whether a speeding problem exists at a site, it is sufficient to collect data on only a sample of passing vehicles, unless equipment and budget permit otherwise. Typically, a sample of 50 to 100 vehicle speeds is sufficient for the purposes of a spot speed study. Of course, the type of vehicle whose speed is measured may be relevant in determining the extent of the speeding problem. Passenger vehicles may be more likely to speed in many settings than heavy vehicles. With this in mind, it may be decided that only certain vehicles should be sampled. The study itself should be conducted during the day on a Tuesday, Wednesday or Thursday, in order to capture representative traffic conditions.

Field Data Collection

There are a number of factors to consider in selecting an appropriate site for a spot speed study. Residents of a particular block may be vocal in notifying a practitioner or police of a speeding problem. In such cases, the general study area is known and only selection of the point at which data will be collected is necessary. In other cases, the general area of the speeding problem is more likely to be unknown, and a specific point where data collection should occur must be investigated in more detail. This will likely rely on observation and experience.

In conducting the spot speed study using pneumatic road tubes, data collection may occur wherever the practitioner wishes, provided the traffic stream of interest passes over the tubes. For radar studies, the data collector should be out of sight of motorists so they don’t slow down out of fear of being ticketed. Also, it should be mounted at the proper angle to traffic as recommended by the manufacturer. Stopwatch studies should also, to the extent possible, be conducted with concealed data collectors, while maintaining a clear line of sight of the passing vehicles.

The spot speed study will produce different types of data. Pneumatic road tube counters will record the travel time of a vehicle passing through a speed trap and process this information to produce vehicle speeds. Radar guns produce a vehicle speed reading, which is typically recorded on paper and later entered into an electronic database such as an Excel spreadsheet. Finally, manual stopwatch methods require setting up a visual speed trap, typically involving colored tape marking points along a road that are a known distance apart. An observer operating the stopwatch records when vehicles pass the two points and records the time on paper. These records are later processed to determine vehicle speed. The calculations required to make this determination are outlined by Smith and McIntyre (**Error! Bookmark not defined.**), as well as other sources such as traffic engineering textbooks.

Field data collection using pneumatic road tubes is straightforward. Following manufacturer guidance, the equipment is set up in the field and left to record vehicle speeds for a given period of time. When the data collection period is over, the equipment is removed and the counter brought back to the office for data download and analysis.

Radar methods require the data collector to point the radar gun at the vehicle of interest, obtain its speed, and then record that speed to a data sheet. Templates for this purpose are provided by numerous sources, such as the Manual of Transportation Engineering Studies (60). Similarly, the stopwatch method requires the data collector to record vehicle travel times through a speed trap on a paper form; sample forms are available from various sources.

Data Processing and Analysis

Following field data collection, the data is analyzed following certain procedures. In the case of pneumatic tube counts, the data is downloaded from the data recorder. In the case of radar and stopwatch procedures, the data is transferred from hard copy data collection sheets to an electronic format. In the case of stopwatch data, this is followed by the conversion of travel time readings into vehicle speeds. The equation for this conversion is as follows:

$$speed = \frac{speed\ trap\ distance}{vehicle\ travel\ time}$$

Depending on the data collection site, issues such as parallax may be present, which require correction. A discussion of such corrections is beyond the scope of this text, and the reader is encouraged to review such discussions in references, such as Roess, et al. (**Error! Bookmark not defined.**).

In analyzing spot speed data, one of the first and most widely employed steps is to develop a speed distribution table. Such a table presents the frequency of vehicles observed traveling at a specific speed, the cumulative frequency of vehicles observed from the initial speed, and the cumulative percentage of vehicles observed. In the context of this work, such a table would provide the practitioner with the 85th percentile speed for the study site, with which a determination could be made as to whether a radar speed sign is warranted based on the expected impacts of that signage on reducing speeds. For more detail on completing the table described here, the reader is encouraged to reference traffic engineering handbooks or textbooks.

In addition to identifying percentile speeds, the practitioner will likely also wish to determine the mean speed for the site. This is calculated by summing all observed speeds and dividing by the number of observations collected. In equation form, the mean speed is computed as follows:

$$mean\ speed = \frac{sum\ of\ observed\ speeds}{sum\ of\ observations\ made}$$

From the mean speed, the practitioner can determine whether a speeding problem exists at the site and whether a radar speed sign will adequately address the problem.

Finally, in the context of this work, it is useful to determine the percentage of vehicles exceeding the posted speed limit. This determination is straightforward and is calculated as follows:

$$percentage\ speeding = \frac{sum\ of\ vehicles\ exceeding\ speed\ limit}{sum\ of\ total\ vehicles\ observed}$$

With this information a practitioner can determine whether a radar speed sign is warranted, based on speed reductions that can be expected by using the signs. In other words, if a radar speed sign in a particular application has been shown to produce a reduction of X percent in numbers of vehicles exceeding the posted speed limit, and the observed percentage of vehicles exceeding the speed limit from the spot speed study is similar, use of a radar speed sign may be warranted. Of course, the percent of vehicles exceeding the posted speed limit identified during the spot speed study may be so great that other countermeasures should be considered.

Conclusion

Based on the results of the spot speed study, the practitioner will be in a position to determine whether a speeding problem exists and the extent of the problem (e.g., by how much mean speeds exceed the posted speed limit). By knowing the extent of the problem, the practitioner can consult the guidance provided to determine the expected impact radar speed signs might have on the metric (mean speeds, percent speeding or 85th percentile speeds). In some cases, the impact of radar speed signs may warrant the use of signage. In other cases, such a significant speeding problem may exist that alternatives means such as enforcement may be required, either separately or in combination with radar speed signs.

12. APPENDIX E: SUNNYVALE, CALIFORNIA, SIGN SPECIFICATIONS

SPEED FEEDBACK (RADAR SPEED) SIGNS

1. GENERAL DESCRIPTION

The speed feedback (radar speed) signs shall have multiple display modes of operation. The letters and numerals of the sign shall be amber LED (Light Emitting Diode) clusters. The LEDs shall be ITE (Institute of Traffic Engineers) amber and shall have a wavelength from 590 to 600 nanometers and utilize AlInGaP technology. The LEDs shall be rated for 100,000 hours or more for continuous illumination. The light intensity shall be 2250 cd/m*m or higher per California test 606. The sign system shall be controlled in all functions by an on-board dedicated computer (controller) that shall be of solid-state design and be removable.

The top two rows of the sign shall be a minimum of letters six inches (6") high by four inches (4") wide for two lines display. The messages shall read at a minimum "SPEED LIMIT," "YOUR SPEED" and "SLOW DOWN." It is preferable that the upper display shall be a full LED matrix display capable of displaying user defined messages. There shall also be a "blank-out" display, which has no visible message. The third and bottom row of the sign shall be numerals at least sixteen inches (16") high by nine inches (9") wide. The numeric display range shall be 0 to 99 miles per hour, with two numerals from zero to nine. The numeric portion of the sign shall be capable of changing according to the speed of an approaching vehicle, stating the speed limit or a "blank-out" display, which has no visible message.

The sign shall be capable of displaying variable messages that can be programmed via RS-232 hardwire and Wi-Fi connectivity using a Windows device such as a mini-laptop and Windows desktop application.

2. GENERAL SPECIFICATION

Overall sign dimensions: (40 – 50)" height x (25-32)" width x (2-6)" depth.

Messages to read: 1st – "SPEED LIMIT," 2nd – "YOUR SPEED", 3rd – "SLOW DOWN" (optional) and 4th – a "blank out" display.

Power: Voltages: 120 VAC, 240 VAC, 12VDC and Solar Powered. THE SIGNS FOR THIS PROJECT SHALL BE POWERED BY 12VDC AND SOLAR POWERED.

Amps: 4.5 amps max @ 12 VDC

Watts: 150 or less.

Radar: Low Power, 24.150 GHz (K-Band) with uni-directional monitoring

FCC Approval: Part 15 Certified, No operating license required

Frame: Heavy duty Welded Aluminum.

Lens: Minimum 3/8" Poly Carbonate

Paint: Gloss Black Powder

3. CONTROLLER

The controller shall have an on board GPS real time clock. The Operation Modes shown below shall be provided, each mode can be set based on time-of-day and shall be programmable via RS-232 hardwire and Wi-Fi, through a Windows Mobile PDA device such as Pocket PC and a Window's desktop application. The controller shall have a minimum of five (5) programmable shutdown/operational times per day.

The controller shall have a smooth analog type dimming capability. Dimming shall have a 5 – 99 selection setting (5 = 5% of full bright or very dim for night use). This setting shall be programmable via RS-232 hardwire and/or Wi-Fi connectivity through a Windows Mobile PDA device such as Pocket PC and through Windows desktop application.

The controller shall have a programmable threshold. This allows a user to adjust the "YOUR SPEED" trip point. Threshold adjustments shall be 1 mile per hour increments. Range is 1 – 99. It shall also be able to provide a "blank out" display at a programmable maximum vehicle speed.

4. OPERATION MODES

Mode Static Display Dynamic Display Flashing Display Definitions

0 SPEED LIMIT YOUR SPEED BLANK Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT VEHICLE SPEED

1 SPEED LIMIT YOUR SPEED SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT VEHICLE SPEED LIMIT

2 SPEED LIMIT SLOW DOWN SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT VEHICLE SPEED LIMIT

3 BLANK SLOW DOWN SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

VEHICLE SPEED LIMIT

4 BLANK YOUR SPEED SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

VEHICLE SPEED LIMIT

5 BLANK SPEED LIMIT SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT SPEED LIMIT

6 BLANK YOUR SPEED SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

VEHICLE SPEED LIMIT

7 BLANK YOUR SPEED YOUR SPEED Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

VEHICLE SPEED VEHICLE SPEED

8 BLANK YOUR SPEED SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

VEHICLE SPEED BLANK

9 BLANK SPEED LIMIT SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT BLANK

10 BLANK SPEED LIMIT YOUR SPEED Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT VEHICLE SPEED

11 SPEED LIMIT YOUR SPEED SLOW DOWN Static: For cars not speeding

Dynamic: For cars exceeding the speed limit

Flashing: For cars exceeding the maximum speed

SPEED LIMIT VEHICLE SPEED BLANK

Notes:

Static Display: Default visual of the sign

Dynamic Display: Display for cars that exceed the speed limit plus threshold speed

Flashing Display: Display for cars that exceed the user-defined maximum speed

Maximum Speed: User-defined speed at which the sign will switch from Dynamic Display to Flashing Display

Threshold Speed: Incremental speed added to speed limit to determine when sign changes to Dynamic Display

5. COMMUNICATIONS

A WiFi and RS-232 hardwire connection to controller using a Windows programming unit shall be provided. The Windows programming unit shall be a WiFi ready mini-laptop. Unit shall be provided with communications/interface software for sign, and communication cable. The communication ports shall allow uploading and downloading of controller data. Data shall include Firmware update, Time of Day, Special Event, Master Shutdown, Peak Speeds, Counts, Maintenance, Defaults and Mode Operation data and reports. If removable flash memory is used for data storage minimum size shall be 4 GB.

6. DATA LOGGING

Data Logging shall contain and report the following information:

Peak Speeds:

1) Peak Speeds logged per day

2) Each Peak Speed shall have a Month, Day, Year, Hour, Minute and second stamp.

Volumes:

1) Counts stored in user-defined bins.

2) Minimum data points = 4 million

3) Each Bin shall have a Month, Day, Year, Hour, Minute and second stamp.

Data gathered shall be logged and formatted such that information can be exported into Microsoft Excel for processing and analysis.

7. WARRANTY

The Sign manufacturer shall provide full warranty and support at no cost to the City for a period of seven hundred thirty (730) days from operational acceptance/activation. The Sign manufacturer shall provide support to the City within twenty-four (24) hours of receipt of a request for information or assistance during the warranty coverage period.

8. MOUNTING ASSEMBLIES

The signs shall be mounted on existing street light poles. The supports and mounting hardware shall conform to State Standard Specifications, Section 86 4.08, Signal Mounting Assemblies or an approved equal. Solar panel mounts shall be side of pole mounts and 30 ft of Liquid-Tite flexible conduit and 35 ft of cabling from the solar panel to the controller cabinet shall be provided per sign

13. APPENDIX F: EXAMPLE SOLAR AND CHARGING CALCULATIONS

This appendix presents detailed design assumptions, conditions, and calculations for reader reference.

Permanent Sign: Solar Panel

This information pertains to the sizing solar panels for permanent radar speed signs. Note all of the following calculations assume the radar sign requires 3 watts average power both day and night.

The battery is sized for 4 days of 24 hour operation with 3 watt average power consumption, day and night operation, without charging. Three watts divided by 12V equals 0.25A average current draw. For 24 hours at 0.25A the current required is 6Ah. Therefore to run the sign for 4 days without any solar charging requires 24Ah. To avoid discharging the battery below 50% charge raises the requirement to a 48Ah battery. Also, battery capacity is reduced by approximately 50% at a temperature of -22°F [8] (61) therefore a 96Ah, minimum, rated battery is recommended for the colder regions of District 2. A battery example is the Sun Xtender PVX-1040T battery whose standard 24 hour rating is 104Ah. Note the Sun Xtender batteries operating temperature rating is -40°C to +72°C.

The rule of thumb for the PV panel size calculation for a remote device is the average current draw times 10, or 0.25A x 10 = 2.5A. The x10 factor accounts for the effects of weather, temperature, season, nighttime loss, etc. on PV panel power production. Another rule of thumb is PV panels produce about 1A for every 15 watts rated power, therefore a panel rated at approximately 37.5 watts is needed. Since a PV panel typically produces 10% to 15% less than rated on a year round average (62) the panel size is approximately 37.5W / 0.85 = 44.1W. An example panel is the Kyocera KC40T which is rated at 43 watts and produces 2.48A at rated power (63).

The solar controller size is determined by the PV panel output, voltage and current, and the battery voltage. Standard practice is to take the short circuit current of the PV panel times 1.25 therefore 2.5A x 1.25 = 3.13A. A three stage solar charge controller rated a 3.13A or above is used, such as the 12V Morningstar SS-6-L which is rated at 6.5A maximum.

Permanent Sign: Charging

The sign’s average power consumption is 3W which requires 3W/12V x 24h = 6.0 Ah a day. For a maximum 50% battery discharge and 50% low temperature battery capacity, the battery must be x4 times larger or 24 Ah minimum. The battery charger is sized to provide approximately 25% of the rated battery capacity (64) or 6A of charge current.

Trailer Sign: Solar Panel General informaiton

It is assumed that the radar sign uses 3W average power both day and night. Three watts equal 250mA at 12VDC; therefore the battery requirement is 0.25Ax24hx7d = 42.0 Ah. For a

[8] Note PV panel output increases with decreasing temperature which is the opposite of batteries.

maximum 50% battery discharge the battery must be x2 times larger or 84.0 Ah minimum. For operation below 0°F two 84.0 Ah batteries are required.

Trailer Sign: Charging

Fifteen percent of 84Ah equals 12.6A therefore a 10.0 A charger is required. It will recharge a 50% charge battery in approximately 5 hours and two batteries over night. The charger shall be a 3-Step regulated charger utilizing bulk, absorption and float charging techniques, appropriate for the battery type. The integral 3-Step regulated charger shall use temperature compensation. The charger must prevent destructive discharge and overcharge.

Trailer Sign: Solar Panel Sizing

The PV panel size calculation starts with the power required which is 3W x 24h = 72.0 Wh/day. Dividing 72.0 Wh/day by 2 hours of maximum solar radiation equals 36.0 W/day, which is the minimum solar power required. With 6 cloudy days out of 21, the minimum PV panel size is 36W x 21/15 = 50.4 W. Taking into account weather, panel rating, etc. minimum panel size is 50.4 / 0.78 = 64.6 W. An example is a Kyocera KC-65T rated at 65.0 W and 3.75 A.

Verification of solar radiation availability is done by utilizing the National Renewable Energy Laboratory minimum daily solar radiation per month map[9]. Thirty years of data for northern California shows minimum radiation for northern California is 0 to 2 $kWh/m^2/day$ in January. The Kyocera panel is approximately 5 ft^2 therefore produces $13W/ft^2$ or $140W/m^2$. With 2 hours charging time per day the PV panel would require $280Wh/m^2/day$ solar radiation minimum which is well within the NREL data range.

The solar controller size is determined by the PV panel output, voltage and current, and the battery voltage. Standard practice is to take the short circuit current of the PV panel times 1.25 therefore 3.75A x 1.25 =4.7 A. A 3-stage solar charge controller rated a 4.7 A or above shall be used, such as a Morningstar model SS-6-L which is rated at 12V and 6.5 A maximum.

[9] A resource for solar radiation data for the U.S. can be found at http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/ and http://www.nrel.gov/gis/solar.html. As stated on the map it should not be used for site-specific solar system evaluation because local variations in solar radiation exist that are not evident on the maps.

14. APPENDIX G: RECOMMENDED SIGN SPECIFICATIONS

14.1. Permanent Post-Mounted Signage

Overall Display (California MUTCD compliant)

Parameter	Units	Value Range	Comments
"YOUR SPEED" legend height	Inches	6	Minimum
"YOUR SPEED" faceplate material	N/A	Aluminum	
Faceplate reflective sheeting	N/A	ASTM Type XI	CA MTUCD compliant reflectiveness
Faceplare color options	N/A	White, fluorescent yellow-green, fluorescent orange, yellow	CA MTUCD compliant colors
Warranty	Years	2	Minimum
Setup functions	N/A	Menu driven	Software managed

Speed Display

Parameter	Units	Value Range	Comments
Real time numeric display updating	seconds	1	Shall update displayed speed every second
Programmable display speed thresholds	N/A	Minimum, Limit, Excessive, Maximum	Four thresholds
Programmable display modes	N/A	Constant, blank, flash, stay at maximum	Flash at 60 PM or stay at max when exceeds User Preset Speed Limit setting
ExterN/Al sign configuration software	N/A	MS compatible	Speed thresholds, display modes, schedule times
Configuration device	N/A	PDA or laptop	Windows compatible
Voltage requirements	VDC	12	10.5 to 16
Power requirements	watts	40	Maximum
Hardwire communication connections	N/A	RS-232 or USB	
Wireless communication type	N/A	BlueTooth™	
Wireless communication range	feet	30	Minimum
Warranty	years	2	Parts and labor
Warranty - LED panels	years	4	Minimum
Tests	N/A	Initial segment function test at startup	

Speed Display cont'd

Parameter	Units	Value Range	Comments
LED 1/2 cone angle	degrees	15	Viewing angle
LED luminous intensity	CD	2250 (minimum)	On optical axis
LED luminous intensity @ 15°	CD	100	Maximum at 15 degrees horizontal from optical axis
LED type	N/A	AlInGaP	Amber
LED color	N/A	*ITE amber	590 nm to 600 nm wavelength
LED wiring	N/A	loss or failure of one LED will result in the loss of not more than 6 percent of each segment	
Numeric Display	N/A	2 seven segment solid-state numeric characters	Display digits shall be field-replaceable with the removal of four or fewer exterN/Al fasteners.
Display segments - each	N/A	16 LEDs (minimum)	
Character height	inches	18	Minimum
Maximum display brightness	N/A	settable	To suit various application requirements
Brightness control	N/A	automatic	Provide optimum viewability for all ambient light conditions
Window material	N/A	1/4" minimum thickness clear polycarboN/Ate	10 year guarantee against pixel color fading and yellowing
Cabinet dimensions	inches	36x48x12	(w*h *d) nominal max.
Construction	gauge	11	Aluminum minimum (or comparable in steel)
Hardware	N/A	stainless and brass	Corrosion resistant
Weight	pounds	40	Maximum - not including solar panels or batteries
Operating temperature	°F	-22 to 140	-30 to 60 °C
Wind load rating	MPH	100	Minimum
Electronics enclosure	N/A	NEMA 3R or better	If ventilated, electronic main board shall be conformal coated
Enclosure ID tag	N/A	permanent	Shall include manufacturer's name, model number, serial number, date of manufacture, identification number, rated voltage, current, power and volt-amperes
Controller	N/A	on-board dedicated computer	Controls all sign system functions, solid state design, removable
Controller display	N/A	dedicated 2 line LCD	Backlight for night time operation

Radar

Parameter	Units	Value Range	Comments
Type	N/A	Internal, approach only	
Detection range	mph	5 to 100	
Distance range	feet	1400 typ.	1000 minimum
Operating voltage	VDC	10.8 to 16.8	12 VDC nomiN/Al
Operating temperature	° F	-22 to 140	-30 to 60 °C
Accuracy	mph	+/- 1	
Band Type	N/A	K	
Frequency	GHz	24.15 +/- 0.1	
Beam width	degrees	12	Nominal
Transmit power	mW	25	Maximum
FCC Acceptance	N/A	Part 15 Certified	No license required

Solar Charging

Parameter	Units	Value Range	Comments
Battery type - sealed	VDC	12 deep cycle	Valve-Regulated Absorbtion Glass Mat (VR-AGM)
Battery capacity	Ah	96 minimum	
Photovoltaic type	N/A	Crystalline silicon	Or equivalent
PV panel size	watts	43	Minimum
PV charge controller size	amps	2.5	Minimum
Photovoltaic controller	N/A	LCD display	Manages solar energy input to battery, intelligent shutdown at low voltage point

Pole and Mounting Hardware

Parameter	Units	Value Range	Comments
Pole type	N/A	Type 15	Type 30 slip base
Hardware	N/A	Stainless, brass or galvanized	Corrosion resistant

Options

Parameter	Units	Value Range	Comments
Grid Charging	VAC	120 and 240	
Battery size	Ah	42 minimum	VR-AGM type, 1 day cap.
Battery charger	amps	6 maximum	3-stage type
Cellular modem	N/A		Enables remote programming and monitoring, models specific to cellular carrier
"YOUR SPEED" legend height	inches	8	For speeds faster than 45 mph
Display height	inches	20	For higher speed locations
Window material	N/A	Smoked polycarbonate	10 year guarantee against pixel color fading and yellowing
Electronics enclosure	N/A	NEMA 4	
Controller display	N/A	Dedicated 3 line LCD	Backlight for night time operation
Controller clock		On board GPS real time	
ExterN/Al sign configuration software	N/A	Palm OS	Speed thresholds, display modes, schedule times
Extended warranty	years	1	Parts and labor
Communication Type	N/A	WiFi	
Color	N/A	white	Powder coat
Data logger	N/A	Peak speed with month, day, year, hour, minute, second stamp	4 million data points minimum storage
Speed data collection software	N/A	Include with data logger	Export data to Excel

14.2. Trailer-Based Signage

Overall Display (California MUTCD compliant)

Parameter	Units	Value Range	Comments
"YOUR SPEED" legend height	inches	6	Minimum
"YOUR SPEED" faceplate material	na	Aluminum	
Faceplate reflective sheeting	na	ASTM Type XI	CA MTUCD compliant reflectiveness
Faceplate color options	na	White, fluorescent yellow-green, fluorescent orange, yellow	CA MTUCD compliant colors
Warranty	years	2	Minimum
Setup functions	na	Menu driven	Software managed

Speed Display

Parameter	Units	Value Range	Comments
LED 1/2 cone angle	degrees	15	Viewing angle - maximum
LED luminous intensity	CD	2,250	On optical axis
LED luminous intensity @ 15°	CD	100	Maximum at 15 degrees horizontal from optical axis
LED type	na	AlInGaP	
LED color	na	*ITE amber	590 nm to 600 nm wavelength
LED wiring	na	Loss or failure of one LED will result in the loss of not more than 6 percent of each segment	
Numeric Display	na	2 seven segment solid-state numeric characters	Display digits shall be field-replaceable
Display segments - each	na	16 LEDs	Minimum
Character height	inches	18	Minimum - appropriate for location
Maximum display brightness	na	User settable	To suit various application requirements
Brightness control	na	Automatic	Provide optimum viewability for all ambient light conditions

Speed Display cont'd

Parameter	Units	Value Range	Comments
LED 1/2 cone angle	degrees	15	Viewing angle
LED luminous intensity	CD	2250 (minimum)	On optical axis
LED luminous intensity @ 15°	CD	100	Maximum at 15 degrees horizontal from optical axis
LED type	N/A	AlInGaP	Amber
LED color	N/A	*ITE amber	590 nm to 600 nm wavelength
LED wiring	N/A	Loss or failure of one LED will result in the loss of not more than 6 percent of each segment	
Numeric Display	N/A	2 seven segment solid-state numeric characters	Display digits shall be field-replaceable with the removal of four or fewer exterN/Al fasteners.
Display segments - each	N/A	16 LEDs (minimum)	
Character height	inches	18	Minimum
Maximum display brightness	N/A	Settable	To suit various application requirements
Brightness control	N/A	Automatic	Provide optimum viewability for all ambient light conditions
Window material	N/A	1/4" minimum thickness clear polycarboN/Ate	10 year guarantee against pixel color fading and yellowing
Cabinet dimensions	inches	36x48x12	(w*h *d) nominal max.
Construction	gauge	11	Aluminum minimum (or comparable in steel)
Hardware	N/A	Stainless and brass	Corrosion resistant
Weight	pounds	40	Maximum - not including solar panels or batteries
Operating temperature	°F	-22 to 140	-30 to 60 °C
Wind load rating	MPH	100	Minimum
Electronics enclosure	N/A	NEMA 3R or better	If ventilated, electronic main board shall be conformal coated
Enclosure ID tag	N/A	permanent	Shall include manufacturer's name, model number, serial number, date of manufacture, identification number, rated voltage, current, power and volt-amperes
Controller	N/A	On-board dedicated computer	Controls all sign system functions, solid state design, removable
Controller display	N/A	Dedicated 2 line LCD	Backlight for night time operation

Speed Display cont'd

Parameter	Units	Value Range	Comments
Wireless communication type	na	BlueTooth™	
Wireless communication range	feet	30	Minimum
Warranty	years	2	Parts and labor
Warranty - LED panels	years	4	Minimum
Tests	na	Initial segment function test at startup	

Radar

Parameter	Units	Value Range	Comments
Type	na	Internal, approach only	
Detection range	mph	5 to 100	
Distance range	feet	1400 typ.	1000 minimum
Operating voltage	VDC	10.8 to 16.8	12 VDC nominal
Operating temperature	° F	-22 to 140	-30 to 60 °C
Accuracy	mph	+/- 1	
Band Type	na	K	
Frequency	GHz	24.15 +/- 0.1	
Beam width	degrees	12 (nominal)	
Transmit power	mW	25 max.	
FCC Acceptance	na	Part 15 Certified	No license required

Batteries and Solar Panels

Parameter	Units	Value Range	Comments
Battery type - sealed	VDC	12 deep cycle	Valve-Regulated Absortion Glass Mat (VR-AGM)
Battery capacity	Ah	84	2 batteries for below 0 operation
Photovoltaic type	na	Crystalline silicon	Or equivalent
Photovoltaic panel size	watts	65	Minimum
Photovoltaic panel deployment	na	manual	Cable crank, spring-lift assist or similar
PV charge controller	A	4.7	Minimum
Photovoltaic controller	na	LCD display	Manages solar energy input to battery, intelligent shutdown at low voltage point (LVD)

Trailer Construction

Parameter	Units	Value Range	Comments
Design	na	See-through	Avoids hiding workers or pedestrians
Width	inches	84 maximum	Sized appropriately for display size
Weight	pounds	1000	Maximum
Axle capacity	pounds	Appropriate for trailer weight	
Suspension	na	Leaf spring	Torsion suspension improves towability
Wheel size (dia.)	inches	13 to 15	Sized for
Tire size	na	match wheel size	ST rated
Color	na	White	Powder coat
Hitch	na	2" ball class I	Or larger
Chassis	na	Structural steel	Sized for total trailer weight
Fenders	na	Formed steel	Sized to tire size
Outriggers/jacks	na	3 minimum	Screw or slide type plated
Lighting	na	Tail, stop, turn	Shall meet all US DOT safety standards for highway use
Wiring	na	All wiring to be concealed in frame	Vandal resistant
Display deployment	na	Winch or spring-lift assist	
Battery cabinet	inches	Sized to battery requirements	
Detachable speed limit sign	na	MUTCD compliant	Sized for deployment application

Options

Parameter	Units	Value Range	Comments
Grid charging	VAC	120 and 240	
Battery size	Ah	84	VR-AGM
Battery charger	amps	10	3-stage type
Remote access and configuration	na	cellular modem	Enables remote programming and monitoring, models specific to cellular carrier
"YOUR SPEED" legend height	inches	8	Requires increased LED power
Display height	inches	20	For higher speed locations
Window material	na	smoked polycarbonate	Requires increased LED power
Electronics enclosure	na	NEMA 4 or 4R	
Controller display	na	dedicated 3 line LCD	Backlight for night time visibility
Controller clock		on board GPS real time	
External sign configuration software	na	speed thresholds, display modes, schedule times	Palm OS
Draw bar (tongue)	na	removable	Theft prevention
Suspension	na	torsion	Improved towability
Wheel lock	na	chain near each tire	Theft prevention
Storage cabinet	na	lockable, steel, possibly separate part of battery cabinet	
Extended Warranty	years	1 minimum	Parts and labor
Communication Type	na	WiFi	
Color	na	Orange	Powder coat
Data logger	na	Peak speed with month, day, year, hour, minute, second stamp	4 million data points minimum storage
Speed data collection software	na	Include with data logger	Export data to Excel

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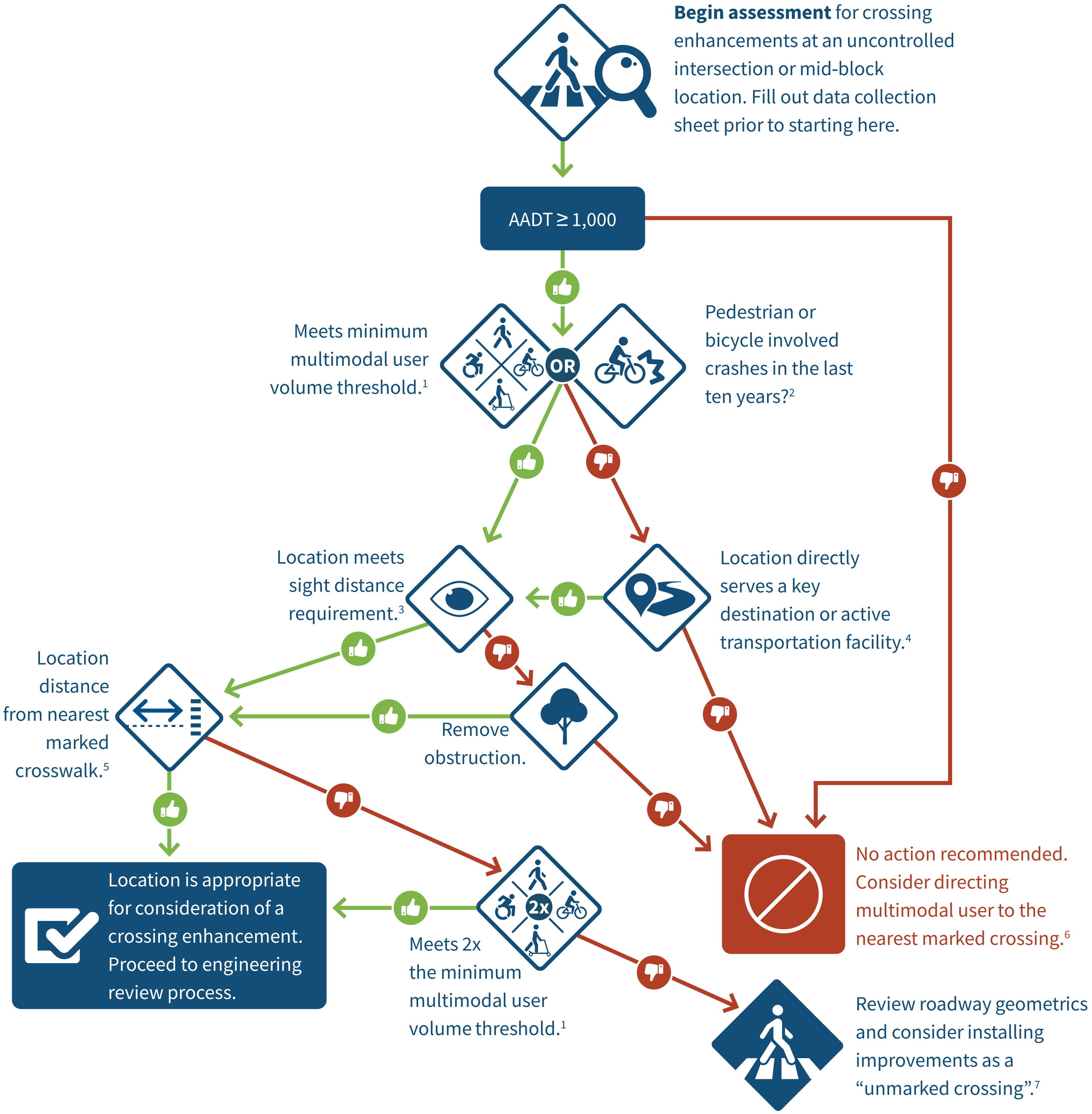
APPENDIX C - CROSSING ENHANCEMENT FLOWCHART - DAKOTA COUNTY



Notes

[1] Multimodal user crossing demand during a 24-hour period meets one or more of the following:

- 1 hour: 20 crossings per hour
- 2 hours: 15 crossings per hour
- 3 hours: 10 crossings per hour

Total number includes vulnerable populations after applying a conversion factor of 1.33 to the sum of those users (i.e., children/young adults (ages 0-17), older adults (60+), and persons with disabilities).

[2] ≥1 preventable crash involving a multimodal user at the roadway crossing location under review in the last ten years. Review crash history and remove preventable crashes (e.g., impaired driver, etc.) from consideration.

[3] Use stopping sight distance to the point of crossing using applicable guidance for the roadway using AASHTO's A Policy on Geometric Design of Highways and Streets.

[4] Key destinations must be existing (or proposed per staff review to be compliant) and could include, but are not limited to, a school, hospital, senior center, recreation or community center, library, park, bus stop or transit center, key activity center, destination, and/or land use subject to staff review. Active transportation facilities may include a sidewalk, multiuse trail, shared use path, or greenway adopted by Dakota County plan or other local document subject to staff review.

[5] Adequate distance from the nearest marked crosswalk per the contextual review and engineering judgment described in the report document. The nearest marked crosswalk must be consistent with the guidelines defined in the report.

[6] Nearest marked crossing must be consistent with the guidelines defined by this document.

[7] An "unmarked crossing" is any treatment that improves a person's ability to cross a roadway, short of a marked crosswalk with signage or other enhancements detailed in Step 3 of the engineering review process. Installation of this type of crossing is subject to staff review and engineering judgement and must include ADA-compliant curb ramps, crossing warning signage, and geometric improvements if applicable in Step 2 of the engineering review process. No markings or additional signage are provided to attract or recommend that multimodal users cross at the location. The crossing is intended to operate as an improvement for a low multimodal user volume crossing where those users are already crossing and will continue to cross at this location.

APPENDIX D - WRIGHT COUNTY'S MARKED CROSSWALK POLICY

Wright County Marked Crosswalk Policy

Pedestrians are legitimate users of the transportation system, and they have the right to cross roads safely. Wright County Highway Department has the responsibility to ensure that the placement of marked crosswalks are in the correct locations that will help to accomplish this.

The Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) states that crosswalk pavement markings should not be placed indiscriminately and an engineering study should be completed when crosswalk marking are being contemplated at a crossing. Defining where to place pedestrian crossing facilities, including markings, signs, and/or other devices depends on many factors, including pedestrian volume, vehicular traffic volume, sight lines, and speed.

1. POLICY

It is in the interest of pedestrian safety that Wright County have specific criteria set forth to ensure that marked crosswalks are allowed only where it is in the best and safest locations for pedestrians to cross the roadway. In most cases, marked crosswalks are best used in combination with other roadway treatments (e.g., locations with stop signs, traffic signals, curb extensions, raised crossing islands, roadway narrowing, enhanced overhead lighting, traffic calming measures, etc.). Marked crosswalks should be thought of as one of a progression of design treatments. These provisions are provided for use by the County Engineer in regulating the location, design, and the method of installation in a uniform manner of marked crosswalks. It also provides for responsibilities between local government units or school districts and Wright County.

2. DEFINITIONS

Marked Crosswalk

For the purposes of this policy, a "Marked Crosswalk" is one that is identified by the use of pavement markings, on the roadway. These markings may include but are not limited to paint, thermoplastic materials, plastic tape, and other acceptable materials. As a supplement to pavement markings, traffic signs and pedestrian activated flashing signs or beacons may also be used to further identify the crossing.

County State Aid Highway (CSAH)

The more heavily traveled routes under County jurisdiction. In Wright County all CSAH's have either one or two digits (e.g. CSAH 3 or CSAH 35).

County Road (CR)

The lesser traveled routes under County Jurisdiction. In Wright County all CR's have three digits (e.g. CR 147).

<u>Table 1. FHWA Safety Guidance Table</u>

This is a matrix of recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled intersections. Sound engineering judgment must be used prior to the installation of any marked cross walk.

3. SCOPE

This policy will apply to all County State Aid Highways and County Roads under the jurisdiction of the Wright County Board of Commissioners and their designee, the Wright County Highway Engineer.

4. GENERAL CRITERIA

In general, a crosswalk should be viewed as a channelization device rather than a safety device. Marking a crosswalk does not increase the safety of pedestrians. Research studies suggest that marked crosswalks may give pedestrians a false sense of security. Pedestrians often step off the curb into the crosswalk, expecting the approaching drivers to stop. The crosswalk markings, however, may not always be readily visible to drivers from a safe stopping sight distance. As a result, drivers sometimes are unable to or fail to stop. Although drivers, by law, must stop and yield the right-of-way to pedestrians at crosswalks, pavement markings do not provide protection against an on-coming vehicle.

Marked pedestrian crosswalks may be installed to delineate preferred pedestrian paths across the roadways without the need for consideration of other criteria, at locations that are controlled intersections (stop signs or traffic signals).

It is not necessary nor is it required to install Pedestrian Crossing signs at intersections controlled by stop signs. Pedestrian Crossing signs shall not be installed at Traffic Signals.

<u>To be considered for a marked crosswalk at an uncontrolled intersection, and in order to provide the safest possible locations for pedestrians to cross the roadway, the following conditions shall exist:</u>

Speed Limit - The authorized posted speed limit shall not exceed 40 mph.

Must meet either a “C” or “P” condition as listed in Table 1.

If an “N” condition exists, then either a push button on demand, “Flashing Light” or a “Blinker” sign shall be installed at the crosswalk. All costs for the push button on demand blinker sign or beacon shall be as agreed upon by the city and/or school district and Wright County per the County’s cost sharing policy.

Sidewalk - When providing a marked crosswalk for a pedestrian, it is important that the pedestrian is properly channeled and has a safe place to go after crossing the street. Therefore, there shall be a sidewalk or other pedestrian type path on both sides of the road.

Sight Distance - A minimum sight distance of 325 feet shall be required, (to provide a cushion for the pedestrian, this sight distance was computed using a stopping sight distance formula for 40 mph on a flat surface, sight distances for downhill grades shall be adjusted accordingly).

School Crossings - Crosswalks that are intended mainly for the use of elementary age school students, **will require crossing guard(s)**, during peak crossing periods. The type (adult or student) and the number of crossing guards shall be determined by the local school (adult crossing guards are recommended).

Parking - It is strongly recommended that parking be eliminated on the approach to Crosswalks at un-controlled intersections, to improve visibility between pedestrians and motorists. During the review process by the County, this may be a requirement for authorization.

5. RESTRICTIONS

Mid-block Crosswalk Mid-block crosswalks shall not be allowed.

6. RESPONSIBILITIES OF LOCAL GOVERNMENTS AND SCHOOLS

The following shall be requirements of Local Government Units (i.e. Cities and Townships) and School Districts for crosswalks on either County State Aid Highways or County Roads in Wright County:

- Submit a written request for a marked crosswalk to the County Highway Department for review. The request shall include a map or sketch of the proposed crosswalk location and documentation or reasoning for a marked crosswalk. This may include an engineering analysis or one may be required.

- If a marked crosswalk request is approved, the local government unit or school district shall complete and sign a marked crosswalk application form.

- The local government unit or school district shall not begin installing a marked crosswalk until they receive a completed and authorized crosswalk permit from the Wright County Highway Department.

- All work performed and costs associated with the installation and maintenance of the marked crosswalks shall be the sole responsibility of the local government unit or school district. Installation of the crosswalks shall conform to the most current edition of the Minnesota Manual on Uniform Traffic Control Devices (MMUTCD) and are subject to the review and approval of the Wright County Highway Department.

- If signing is required or requested, the local government unit shall complete an application for "Pedestrian Crossing Signing on County Highways". Signing by the local government or school district shall be done through a special Pedestrian Crossing sign permit.

- Installation specifications for push button on demand blinker signs or beacons shall be approved by the County prior to installation.

- Only authorized marked crosswalks will be allowed on county highways. All un-authorized marked crosswalks shall be removed by the local government unit or school district at their cost and expense.

- School crosswalks used by elementary-age school children **will require crossing guard(s)**, during peak crossing periods and all work and associated costs for staffing of the school crosswalks shall be the sole responsibility of the school district. The school districts shall also be responsible for properly training and supervising the crossing guards. Research has shown that the use of crossing guards is the single most effective way to safely cross school children across the road.

- The cities, townships and school districts shall indemnify and hold Wright County harmless from any and all claims related to the installation, maintenance, engineering and staffing of crosswalks currently existing or installed pursuant to this policy.

- Failure of the local government unit or school district to properly maintain the marked crosswalk shall result in revoking authorization for said crosswalk. Any costs incurred by Wright County in revoking and/or removing the marked crosswalk and signing shall be paid the local government unit or school district.

7. RESPONSIBLITIES OF WRIGHT COUNTY

- The County shall respond to all marked crosswalk requests. The County Highway Department will review the requests and determine if they qualify based on the criteria in this policy.

- If the County approves a marked crosswalk request, the County shall process a marked crosswalk authorization form and return a marked crosswalk permit to the local government unit or school district.

- Upon completion of the marked crosswalk installation by the local government unit or school district, the County will review the marked crosswalk for compliance with the most current edition of the Minnesota Manual on Uniform Traffic Control Devices.

- The County will be responsible for signing all authorized marked **school** crosswalks.

- The County will replace marked cross walks removed by County pavement preservation practices, i.e. overlays, seal coating or micro surfacing.

- The County may consolidate multiple crossing points on county highways at the same intersection.

- All previously authorized crosswalks are subject to review as roadway conditions and pedestrian/vehicle traffic patterns change.

- All costs associated with the removal of the un-authorized crosswalks will be borne by the local government unit or school district.

8. IN-STREET PEDESTRIAN CROSSING SIGNS

The current Minnesota Manual on Uniform Traffic Control Devices (MMUTCD) has approved the use of the In-Street Pedestrian Crossing sign, provided that the local units of government or school districts follow the procedures and/or requirements of the governing road authority. Should the use of this sign be revoked in future editions of the MMUTCD, then this section shall be null and void and all permits issued for the use of this sign shall be revoked.

9. ADMINISTRATION

1. The Traffic Engineering Section of the Wright County Highway Department will be responsible for administering this policy.

2. Adoption of this Policy supersedes the previous policy as adopted on September 6, 1988.

Adopted this 14th day of August 2007 by the Wright County Board of Commissioners.
Amended this 30th day of October 2007 by the Wright County Board of Commissioners.
Amended this 22nd day of June 2010 by the Wright County Board of Commissioners.
Amended this 27th day of March 2018 by the Wright County Board of Commissioners.

Table 1: FHWA Safety Guidance Table

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT > 9,000–12,000			Vehicle ADT > 12,000–15,000			Vehicle ADT > 15,000		
	Speed Limit*											
	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median**	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

*Where the speed limit exceeds 64.4 km/h (40 mph), marked crosswalks alone should not be used at unsignalized locations.
**The raised median or crossing island must me at least 1.2 meters (4 feet) wide and 1.8 meters (6 feet) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and Amerian Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvements, to improve crossing safety for pedestrians.

Treatment	Advantages	Disadvantages	Recommended Locations	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate	Cost
Center Median with Refuge Island	• Decreases pedestrian crossing distance • Provides higher pedestrian visibility • Reduces vehicle speeds approaching the island • Reduces conflicts • Increases usable gaps • Reduces pedestrian exposure time	• May make snow removal more difficult • May be a hazard for motorists • Small islands not recommended on high-speed roadways (>40 mph)	• Wide, two-lane roads and multilane roads with sufficient right-of-way	34%	29%	Variable depending on length
School Crossing Guards	• Inexpensive • Provides higher pedestrian visibility • Highlights when a pedestrian crossing is being used	• May require trained staff or local law enforcement, especially on high-speed and high-volume roadways	• At school locations	NR	86%	Variable
Pedestrian Crossing Flags	• Inexpensive • Provides higher pedestrian visibility to drivers assuming the flag is held in a noticeable location	• No effect at night • Requires pedestrians to actively use a flag • Can be easily removed/stolen • Shorter crossings are preferred	• Downtown/urban locations • High pedestrian volume locations • Across low-speed (<45mph) roadways	65%	74%	<$500
Warning Sign with Edge Mounted LEDs	• Highlights a crossing both at night and during the day	• Requires pedestrian activation • Minimal to no effect on speed	• In conjunction with in-road warning lights • Downtown/ urban conditions	NR	28%	$3,000–$8,000
In-Road Warning Lights	• Highlights a crossing both at night and during the day • Provides higher driver awareness when a pedestrian is present	• Snowplows can cause maintenance issues • No effect when road surface is snow covered • Requires pedestrian activation	• Downtown/urban conditions	NR	66%	$20,000–$40,000
Pedestal Mounted Pedestrian Flashing Signal Beacons	• Provides higher driver awareness when a pedestrian is present	• Requires pedestrian activation • Not advisable on multilane streets • Not shown to reduce crashes	• Low-speed school crossings • Two-lane roads • Midblock crossing locations	NR	57% (two-lane, 35mph)	$12,000–$18,000
Pedestrian Overhead Flashing Signal Beacons	• Provides higher driver awareness when a pedestrian is present	• Requires pedestrian activation	• Multilane roadways • Mid-block crossing locations • Lower speed roadways	active 47% passive 31%	active 49% passive 67%	$75,000–$150,000
Rectangular Rapid Flash Beacons (RRFBs)	• Provides higher driver awareness when a pedestrian is present • Increases yielding percentage • Increases usable gaps • Reduces probability of pedestrian risk taking • Can be seen from 360 degrees	• Requires pedestrian activation	• Supplement existing pedestrian crossing warning signs • School crossings • Midblock crossing locations • Low- and high-speed roadways	84%	81%	$12,000–$18,000

NR = No research found on effect to yielding rate

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