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Effectiveness of Dynamic Speed Feedback Signs

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16. Abstract
This study uses published research to perform a comprehensive, quantitative review of the effectiveness of dynamic speed feedback signs (DSFSs) where effectiveness was measured by vehicle speed reductions. In 2019 over one-quarter (26%) of all fatal crashes were speeding-related, and speeding-related vehicle crashes cost society hundreds of billions of dollars each year. Lowering excess speeds to reduce these human, societal, and economic costs is therefore a major focus of safety officials and highway engineers. This study focuses on DSFSs, which present drivers with real-time feedback on their speed. This report presents evidence that DSFSs can be effective in reducing mean speeds, 85th percentile speeds, and the percentages of drivers over the speed limit in a range of contexts. Across all types of vehicles and different installation locations, the clear majority of studies found significant reductions in speeds at the DSFSs when the DSFSs are activated. Overall, reductions of 4 mph at the DSFS were estimated for passenger vehicles as a result of DSFS installation, and reductions between 2- to 4 mph at the DSFS were estimated across all vehicle types in the different contexts assessed. As reductions in speed of just a few mph can significantly reduce injury from crashes, these effects demonstrate that DSFSs can be effective tools in saving lives.

This reported is accompanied by its first volume, *Effectiveness of Dynamic Speed Feedback Signs, Volume I: Literature Review and Meta-Analysis*.

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Executive Summary, Volume II

This report reviews the published literature on the effectiveness of dynamics speed feedback signs (DSFSs) in reducing vehicle speeds. In Volume I, the literature review summarized the number of significant results found in studies of DSFS in a variety of contexts. It covered 43 publications and presented a unified framework for the numerous hypotheses that have been tested. The review concluded that strong support for the effectiveness of DSFSs was found when sufficient data were available, with particularly strong support for the activation effect of DSFSs. The meta-analysis in Volume I presented a statistical analysis of the effectiveness of DSFS, showing 2 to 4 mph reductions in speed across vehicle types and safety focal points. The meta-analysis analyzed data taken from the published studies in the literature review.

This volume includes supplemental information to provide further context for those results. Appendix A presents a series of tables showing the number of study sites in each publication that support each hypothesis, in each safety focus. These tables serve as the underlying data in the vote count section of the literature review.

Appendix B provides detailed examples of the type and configuration of DSFSs. The figures demonstrate the range of DSFS configurations that have been employed, including DSFS that include changeable messages, mobile DSFSs, and additional graphical features such as curve symbols.

Appendix C provides further details on the methods used to review each article. In particular, the article review template details how information was organized when reviewing each article, including the study design features, how studies were summarized, and how study schematics were tracked.

Finally, the greatest level of detail is provided in the annotated bibliography. Studies varied substantially in design and objective. The annotated bibliography gives highway engineers and safety officials comprehensive records of the 43 publications reviewed in a consistent format.

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Appendix A. Index of DSFS Features

Appendix A presents a series of tables showing the number of study sites in each publication that support each hypothesis, in each safety focus area. As an example, consider the study in the first row of Table A1 (Bowie, 2003). There were two analyses undertaken (column labeled "Cases"). These two analyses were reported for both the mean speed at the DSFS (H1: Mean) and the mean speed downstream of the DSFS (H2: Mean). In both cases, there was a decrease ("-") in the mean speed.

Note that this information can be used to determine that studies contributed to which vote count result in the literature review in Volume I. Consider the studies that showed no change in the mean speed at the DSFS (H1). Looking at "H1: Mean" and "0" in the literature review, of the seven results that showed no significant change in speeds, three were reported in one publication (Fontaine, 2008), two in a second (Gambatese & Zhang, 2014), and the final two in a third (Sarasua et al, 2006).

Work Zone

Table A1. Work Zone Studies. ("Mean" represents mean speed; "85th" represents the 85th percentile speed; "Over" represents the percentage of drivers over the speed limit; " ," "0" and "+" represent a decrease, no change and increase in speed.)

Authors	Cases	H1: Mean			H1:85th		H1:Over		H2: Mean			H2: 85th		H2: Over		H3: Mean		H3: 85th		H3: Over	
Change in Speed		-	0	+	-	0	-	0	-	0	+	-	0	-	0	-	0	-	0	-	0
Bowie, 2003	2	2							2												
Brewer et al., 2006	1				1		1					1		1							
Fontaine and Carlson, 2001	2	1	3				2	2	3	1				1	3						
Fontaine, 2008	4																				
Gambatese and Zhang, 2014	2		2			2															
Gambatese and Jafarnejad, 2015	8	8					8														
Hajbabai et al., 2011	6	6			5	1															
Mattox et al., 2007	5	5			5		5		5			5		5							
McCoy and Pesti, 2001	2								2			2		2							
McCoy et al., 1995	2	2					2		2					2							
Medina et al., 2009	24								8	10	6										
Meyer 2000	2	2							2												
Pesti and McCoy, 2011	2								2			2		2		2		2		2	
Reddy et al., 2008	2	2			2		2		2			2		2							
Roberts and Smaglik, 2012	1	1			1		1		1			1		1		1		1		1	
Sarasua et al., 2006	17	15	2		15	2	15	2	15	2		15	2	15	2						
Teng et al., 2009	1	1			1		1		1			1		1							

School Zone

Table A2. School Zone Studies. ("Mean" represents mean speed; "85th" represents the 85th percentile speed; "Over" represents the percentage of drivers over the speed limit; "-," "0" and "+" represent a decrease, no change and increase in speed.)

Authors	Cases	H1:mean			H1:85th		H1: Over		H2:mean			H2:85th		H2: Over		H3:Mean		H3: 85th		H3: Over	
Changes in Speed		**-**	**0**	+	**-**	**0**	**-**	**0**	**-**	**0**	+	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**
O'Brien and Simpson, 2012	2	2			2		2														
Lee et al., 2006	1	1			1				1			1									
Saito and Ash, 2005	8	5		3																	
Jeihani et al., 2012	3	3								3											
Ullmann and Rose, 2003	14	13			14		14														

Transition Zone

Table A3. Transition Zone Studies. ("Mean" represents mean speed; "85th" represents the 85th percentile speed; "Over" represents the percentage of drivers over the speed limit; "-," "0" and "+" represent a decrease, no change and increase in speed.)

Authors	Cases	H1:mean			H1:85th		H1: Over		H2:mean			H2:85th		H2: Over		H3: Mean		H3: 85th		H3: Over	
Changes in Speed		**-**	**0**	+	**-**	**0**	**-**	**0**	**-**	**0**	+	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**
Cruzado and Donnell, 2009	12	12																			
Hallmark et al., 2007	4	4			4																
Hallmark and Hawkins, 2015	6	6																			
Hallmark et al., 2013	3	3			3		3														
Kamyab et al., 2002										1			1	1							
Schoenecker et al., 2008	4	4			4																
Williamson and Fires, 2015	1								1												

[1]For two of the sites no information was reported (Cruzado & Donnell, 2009).

Curved Section

Table A4. Curved Section Studies. ("Mean" represents mean speed; "85th" represents the 85th percentile speed; "Over" represents the percentage of drivers over the speed limit; "-," "0" and "+" represent a decrease, no change and increase in speed.)

Authors	Cases	H1: mean			H1:85th		H1: Over		H2: mean			H2:85th		H2: Over		H3:Mean		H3: 85th		H3: Over	
Changes in Speed		**-**	**0**	**+**	**-**	**0**	**-**	**0**	**-**	**0**	**+**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**
Bertini et al., 2006	2	2							2												
Drakopoulos et al. 2003[1]	1																				
Hallmarks, 2015	22	22			22																
Knapp and Robinson, 2012	3	3			3		3		3			3		3							
Tribbett et al., 2000	10								5	5											
Western Transportation Institute, 2003	2	2			2																

[1]Note that there was a significant decrease in the Drakopoulos et al. (2003) study only for semi-trucks that activated the sign. When only a single case was presented and the evidence from that case was not unanimous, we decided not to include it.

Straight Section

Table A5. Straight Section Studies. ("Mean" represents mean speed; "85th" represents the 85th percentile speed; "Over" represents the percentage of drivers over the speed limit; "-," "0" and "+" represent a decrease, no change and increase in speed.)

Authors	Cases	H1: Mean			H1: 85th		H1: Over		H2: Mean			H2: 85th		H2: Over		H3:Mean		H3: 85th		H3: Over	
Changes in Speed		**-**	**0**	**+**	**-**	**0**	**-**	**0**	**-**	**0**	**+**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**	**-**	**0**
City of Bellvue, 2009	31				31																
Chang et al., 2004	4	3		1																	
City of Englewood, 2006	6																				

Appendix B. Dynamic Speed Feedback Sign Examples

Five examples of various combinations of the above types of DSFS are shown below.

A typical, very simple installation is displayed below in Figure B1 (Bullough et al., 2012). This static DSFS display message is activated when the speed is greater than 30 mph. The display is lighted, but does not indicate the driver's speed nor does it flash. The unit is a fixed one. A speed limit sign is upstream of the DSFS.

Figure B1. Static, lighted DSFS on CMS that does not display speed and does not flash. (Display activated when speed is greater than 30 mph.) (Bullough et al., 2012)

A mobile, lighted DSFS that displays the driver's speed is presented below in Figure B2 (Brewer et al., 2006). The DSFS is downstream from a speed limit sign. It is activated at all times and is often referred to as a speed display trailer.

Figure B2. Mobile, lighted DSFS that displays speed without flashing. (Speed displayed for all drivers.) (Bullough et al., 2012)

Next, consider a mobile, lighted DSFS that displays the driver's speed, but does not flash. The speed of the driver may be the last of several messages displayed when a driver is over the speed limit. This is the case for the sequence of messages in Figure B3 below that was used in one of the studies (Brewer et al., 2006). The first message was displayed to all drivers: (a) "Give us a brake." The second, third, and fourth messages were displayed in sequence as a violator approached the DSFS: (b) "Slow Down," (c) "Your Speed" (d) "(*driver's actual speed*)."

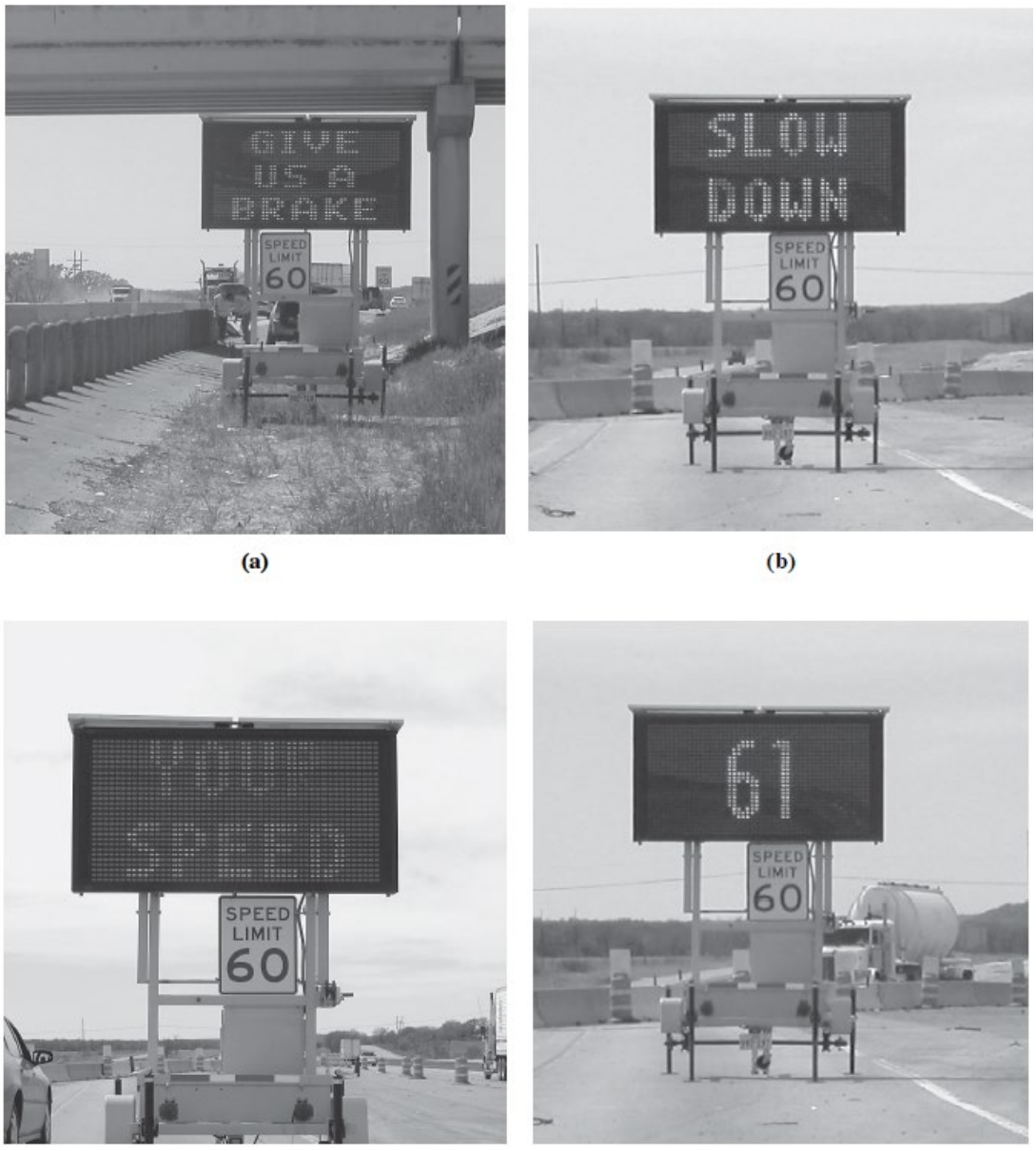


Figure B3. Mobile, lighted, DSFS with multiple messages prior to display of speed – no flashing. [(a) default DSFS message for non-violations; (b) first pass phase for violators; (c) second pass phase for violators; and (d) final phase for violators.] (Brewer et al., 2006)

There also exist examples of dynamic speed feedback signs that do not display the speed, but that do flash when the driver is over the posted speed limit. For example, in one study the top

and bottom lights flashed on a message that said “Slow Down” and that had an icon of a sharp right curve (Figure B4) (Robinson, 2012).

Sign Display #1 - Blank

Measured vehicle speed is less than set speed threshold or no vehicle is present.

Sign Display #2 – Activated with “SLOW DOWN” and Top/Bottom Alternating Lights

Measured vehicle speed is equal to or greater than set speed threshold

Figure B4. Static, lighted DSFS that does not display speed but that flashes, as a dynamic curve warning sign. (Robinson, 2012)

Finally, there are signs that flash the speed for drivers who travel above the speed limit. A simple example is displayed below in Figure B5 (Santiago-Chaparro et al., 2012).

Figure B5. Static, lighted DSFS that displays speed and flashes. (Santiago-Chaparro et al., 2012)

Appendix C. Article Review Template

Each of the 43 included articles reviewed in the annotated bibliography is detailed in Section 5. The template below uses and example article that focused on DSFSs at horizontal curves (Bullough et al., 2012), to demonstrate the review process. We begin each article in the review with information on the study identifying information, relevance screening and quality screening. These have been discussed in the literature review in Volume I.

Features

We continue the review with a simple list of information relevant to the study (Table C1). This list includes five different categories.

1. What hypotheses were evaluated,
2. What dependent variables were used to evaluate the hypotheses,
3. What were the results of those evaluations,
4. What were the characteristics of the study that the practitioner needs to know in order to implement the DSFS in a particular setting, and
5. What are the aspects of the experimental design that the researcher needs to know in order to evaluate the goodness of the study?

Table C1. Features Defining Each Study

Feature	**Study data**
Experimental design	O-X-O
Safety focus	NS
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 level	B
Hypothesis 2 level	B
Hypothesis 3 level	NA
DSFS displays speed	No
DSFS speed lighting	Yes
DSFS flashes (speed or other)	No
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Suburban

Feature	Study data
Sidewalks present	No
Posted speed	30 mph
Sensor positions	Adjacent (328 ft. downstream)
Number of sensors	0,1,1
Sensor types	Radar
Types of treatments	DSFS
Number of sites per treatments	1
Over how long a period is speed measured: O1(interval)	5 hours
How long before activation were speed measures taken: T1(interval)	NS
Over how long a period is DSFS activated: X1(interval)	NS
Time of day when speed measured: a.m./p.m.	Multiple
Time of day when speed measured: peak/off peak	Off peak
Times after activation of DSFS when speed is measured X1(measurements)	NS
How long a time period after DSFS was deactivated intervened between deactivation and measurement: T2(interval)	NA
How long after DSFS removal/deactivation were they taken: O2(interval)	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Nothing reported

Feature	Study data
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

These sections were discussed in detail in the literature review portion of Volume I, in particular:

1. The hypotheses are discussed in detail in Section 2.7,
2. The dependent variables are discussed in Section 2.8,
3. The characteristics of a study that are important to implementation of a DSFS at a location are discussed in Section 2.9,
4. The results of all of the evaluations are separated out by safety focus in Section 2.11, and
5. The information necessary to evaluate the scientific validity of a study is described in Section 2.12.

Summary of Study

Next, we include a summary of the study. This summary follows verbatim below (Bullough et al., 2012).

This study examined the effectiveness of two safety countermeasures. Relevant to this literature review, it evaluated a sign with conditional messages based on driver speed. Initial tests were conducted in controlled field experiments and then follow-up evaluations studied the effectiveness in real-world conditions. The real-world test location for the sign was located along Jordan Road, a small local road in the Rensselaer Technology Park in North Greenbush, New York. The sign was located on the grass adjacent to the road, and no construction work or other activity took place in the road itself during the data collection.

The LED sign was programmed to display several conditional messages based on the speed of the approaching vehicle.

- If a vehicle is going faster than 30 mph: "REDUCE SPEED TO 25 MPH"
- If a vehicle is going 25 to 30 mph: "25 MPH SPEED ZONE"
- If a vehicle is going 20 to 25 mph: (No Message)

- If a vehicle is going less than 20 mph: "25 MPH SPEED ZONE"
- When no vehicles are approaching the sign it rests in a blank display.

Although the original speed limit along this road segment was 30 mph, the speed display sign was set up to encourage driving speeds of 25 mph. Approximately 328 ft. downstream from the display a member of the project team hid behind several trees and an electrical junction box and measured speeds with a radar gun. Further downstream a sign alerted drivers that the speed limit reverted to 30 mph. All measurements were taken in clear weather in the middle of the day to avoid peak rush hour. If vehicles were closely spaced, only the speed of the lead vehicle was measured to ensure independent speed measurements.

Data were collected before and during sign implementation, but the publication did not specify how much time elapsed between the measurements.

- Before: From10 a.m. to 3 p.m., a total of 663 vehicle speeds were measured.
- During: From approximately 9:45 a.m. to 11 a.m., speeds for 108 vehicles were measured.

The measures of effectiveness were mean speed and the standard deviation of speed. The hypotheses investigated were H1B and H2B.

Data reported. Mean speeds and standard deviation, as well as histograms of speed observations.

Results. There was a statistically significant ($p<0.001$) reduction in the mean measured speeds during the installation test compared to the baseline conditions. The speed display messaging appeared to have the intended effect of reducing speeds closer to 25 mph (from a mean of 30 mph and a median of 33 mph), and also reduced the standard deviation of the measured speeds from 7.88 to 4.66 mph.

Statistical Analysis. The publication did not describe the statistical analysis, but it did report that results were statistically significant, implying that the researchers conducted statistical analysis. The authors of this publication indicated that significant speed reductions were achieved at the location of the DSFS and downstream of the DSFS, in line with hypotheses H1 and H2.

Study Schematic

When information is available on the details of the implementation of the study, such as a schematic, we include that for reference as well in the review of the study. For example, below in Figure C1 is an aerial view and map of the general area where the DSFS was installed (Bullough et al., 2012).

Figure C1. Plan view of geographic location of study (Bullough et al., 2012)

Additionally, where more detail is available, information is provided on the location of the DSFS in relation to any upstream and downstream traffic control devices (Figure C2).

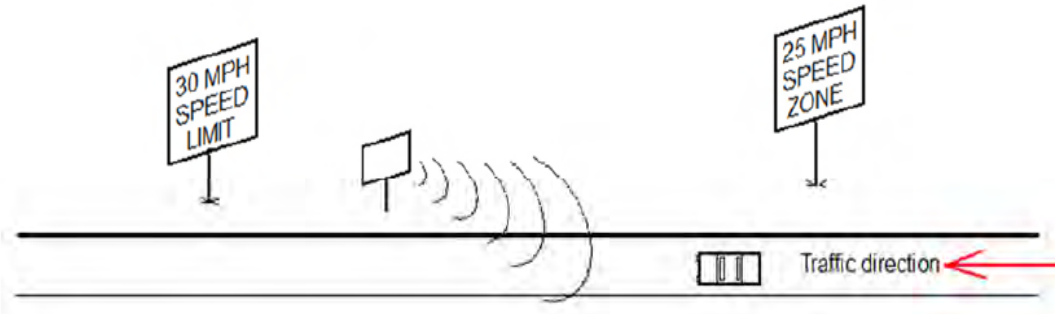


Figure C2. Location of DSFS relative to other traffic control devices (Bullough et al., 2012)

Appendix D. Annotated Bibliography for Review of Dynamic Speed Feedback Signs

This annotated bibliography provides detailed descriptions of the 43 publications in the literature review. Readers are asked to refer to the literature review for discussion of the study goals, hypotheses, and conclusions. This document provides comprehensive detail on individual studies that may be of interest for matching study characteristics and methods with a DSFS site under consideration.

Candidate publications were identified by a search of the following databases: Transport Research International Documentation (TRID), National Transportation Library (NTL), WorldShare, Academic Search Complete, PsycINFO, Web of Science, and Science Direct. The searches were carried out from March 9 to March 16, 2016, by research librarians. A full list of the search terms is provided in Table 1 of the literature review. The search resulted in 108 candidate references. After filtering for domestic sources that report unique data collection efforts, and had data available for analysis, 43 publications were reviewed.

Publications are listed alphabetically by first author. See the References section for bibliographic details on each publication.

Explanation of Annotated Bibliography Fields and Entries

Each of the entries in this annotated bibliography follows the same format. This initial section displays the format along with explanatory notes to clarify the meaning and purpose of each field. Some of the text in the entries that follow is directly pasted from the publication abstracts.

Study Characteristics

Item	Explanation
Authors	The official authors of the publication
Title	Title as recorded in the publication
Publication year	Initial publication year as recorded in the publication

Relevance Screening

Inclusion Criteria	Explanation
Is this study an empirical investigation of the effects of effectiveness of dynamic speed feedback signs?	The criteria in this table were used to screen each publication. Each publication had to meet both criteria in order to be included. Thus, this table is omitted from the final bibliography entries because it would look the same for each entry.
Is the outcome measure crashes, fatal crashes, and/or traffic speeds?	See above.

Quality Screening

Quality Criteria	Explanation
Were the study population and the context of the study well described?	In order to qualify, the publication must describe the following. a. Study population (e.g., passenger vehicles, trucks, both) b. Context i. Posted speed ii. Roadway design iii. Placement of sensors and DSFS iv. Time of day and number of days measurements are taken
Were the exposure variables valid implementations of the conditions that they were meant to represent?	In order to qualify, the following must be true. c. Did the DSFS provide dynamic speed information during the entirety of the treatment conditions? d. Was the DSFS off during the control conditions?
Was the outcome variable both a reliable and valid measure of the outcome of interest?	a. Mean speed, 85th percentile speed, and percentage of drivers exceeding the speed limit were all considered reliable and valid b. Other variables were only included if reliable and valid

For all 43 publications in this annotated bibliography these three questions are answered in the affirmative. The quality screening is thus not shown for each individual study.

Study Features

Feature	Explanation
Experimental design	**Example entry:** O-X-O Describes the temporal sequence of experimental steps. "O" indicates an observation period, and "X" indicates an experimental intervention (DSFS and/or other treatments). In the example, the first "O" indicates an observation period before activating the DSFS. The second "O" indicates an observation period during activation of the DSFS.
Safety focus	Identifies the context of concern explicitly identified by the authors (e.g., work zone, school zone, transition zone, horizontal curve).

Feature	Explanation
Graphic of DSFS available	Indicates whether the publication includes an image of the sign.
Graphic of layout available	Indicates whether the publication includes a map or diagram showing the location of the signs in relation to other traffic elements.
Study restricted to free flow level of service	Notes whether the study only measured vehicles in "free-flow" conditions, meaning that vehicles had enough space around them at a given speed so as to be uninfluenced by the speeds of other vehicles. The exact definition of "free-flow" differs slightly across publications.
Classes of vehicles included	Indicates whether the publication had an explicit focus on one or more vehicle classes (e.g., passenger cars and trucks).
Hypothesis 1 (H1) level	Indicates the type of hypothesis used to test effectiveness at a location adjacent to the DSFS during activation ("activation hypothesis"). See other documentation for more detailed explanation of hypothesis types and codes.
Hypothesis 2 (H2) level	Indicates the type of hypothesis used to test effectiveness at a location downstream of the DSFS during activation ("downstream activation hypothesis"). See other documentation for more detailed explanation of hypothesis types and codes.
Hypothesis 3 (H3) level	Indicates the type of hypothesis used to test effectiveness at a location adjacent to the DSFS after it has been deactivated ("deactivation hypothesis"). See other documentation for more detailed explanation of hypothesis types and codes.
H1: Mean speed	For each combination of hypothesis type and dependent variable, the following entries summarize significant results reported in the publication. Here, for example, if a study reported a significant change in the mean speed during activation as compared to before activation at a location adjacent to the DSFS, this field would indicate that there was a significant difference.
H1: 85th percentile speed	See above.
H1: Percentage of drivers over speed limit	See above.
H1: Distribution of speed	See above.
H2: Mean speed	See above.

Feature	Explanation
H2: 85th percentile speed	See above.
H2: Percentage of drivers over speed limit	See above.
H2: Distribution of speed	See above.
H3: Mean speed	See above.
H3: 85th percentile speed	See above.
H3: Percentage of drivers over speed limit	See above.
H3: Distribution of speed	See above.
DSFS displays speed	Indicates whether the sign displays numerals to show each driver the measured vehicle speed. This is in contrast to a sign that provides feedback to the driver (e.g., displaying "slow down" in response to speeds above a certain threshold) but does not display the exact speed.
DSFS speed lighting	Indicates whether the sign had any lights (e.g., numbers on the sign arranged as a matrix of lights or retroreflective).
DSFS flashes (speed or other)	Indicates whether the sign has any flashing lights (numbers or other lights).
Mobile DSFS units	Indicates whether the sign is portable (e.g., a speed display trailer)
Roadway type	Categorizes the road into one of several major types (e.g., freeway, arterial, collector, and local).
Area type (location)	Categorizes the location as either urban, suburban, or rural.
Sidewalks present	Indicates whether there are pedestrian sidewalks.
Posted speed	Denotes the regulatory speed for the roadway at the location of the DSFS (adjacent).
Sensor positions	**Example entry:** Adjacent (328 ft. downstream) Indicates the location of any sensors used to measure speeds in any of three categories: upstream of the DSFS, adjacent to the DSFS, or downstream of the DSFS. The categorization here is consistent with the way that the authors categorized their sensors. This means that in some cases an "adjacent" sensor may actually be located slightly downstream of the DSFS, if the authors argued that it was effectively adjacent (due to delayed driver reaction time, etc.) Not every study had a sensor in all three categories. Missing categories were omitted, such as in the below

Feature	Explanation
	example, which did not have any upstream or downstream sensors.
Number of sensors	**Example entry:** 0,1,0 Lists the number of sensors in each category (upstream, adjacent, downstream)
Sensor types	Indicates the types of sensors the researchers used to gather speed data (e.g., radar).
Types of treatments	This may include DSFS, but may also include other treatments implemented in addition to and simultaneously with the DSFS (e.g., police enforcement).
Number of relevant sites	Indicates the number of unique sites where relevant tests were conducted.
Number of cases	Indicates the total number of unique circumstances for which data were reported (e.g., the number of sites multiplied by the number of relevant, unique treatments multiplied by the number of vehicle types separately analyzed)
Duration of measurements before activation ("before" measurements)	Indicates the length of time over which speed measurements were gathered in the baseline observation period (before DSFS activation).
Time interval between "before" measurements and activation	Indicates the amount of time that passed after the last baseline measurement and before DSFS activation.
Duration of activation	Indicates the length of time that the DSFS was activated
Time of day when speed is measured (a.m./p.m.)	Indicates the time of day that speed measurements were taken.
Time of day when speed is measured (peak/off peak)	Indicates whether speed measurements were taken during a peak or off-peak time.
Time intervals at which measurements were taken during activation ("during" measurements)[1]	Indicates the times that speed measurements were taken during activation of the DSFS. For example, an entry of "1, 3, and 6 months," means that measurements were taken after the DSFS had already been continuously operating for one month, and subsequent separate measurements were taken after 3 and 6 months of operation, respectively.

[1] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Explanation
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	Indicates the amount of time that passed after the DSFS was activated and before the subsequent measurement period.
Duration of "after" measurements	Indicates the length of time over which speed measurements were gathered in the observation period following DSFS deactivation.
Meta-analysis data available	Indicates whether data was available for use in the meta-analysis.
Caveats	Indicates whether there were any unique circumstances affecting the usability of the data for the meta-analysis.
Best practices information available	Indicates whether the publication included any practical implementation advice that may be of interest to a transportation agency that is considering using a DSFS.

Summary of Study

This section of each review describes the basic context of the study in narrative form. It also highlights any aspects that were particularly unique.

Data reported. Describes the data that were actually available in the study. Often this did not include all of the stated measures of effectiveness for which the study collected data.

Results. Describes the major findings of the study and any statements of statistical significance, if available.

Statistical Analysis. Summarizes the statistical analyses and tests that the publication authors conducted, as described by the authors.

Study Schematic

Maps and/or diagrams showing the locations of the signs in relation to other traffic elements, if available.

DSFS Graphic

Images of the signs, if available.

1. Addison County Regional Planning Commission, 2013

1.1. Study Characteristics

Item	Response
Authors	Addison County Regional Planning Commission
Title	Effectiveness of Radar Speed Feedback Signs and Other Traffic Calming Techniques
Publication year	2013

1.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Pedestrian area
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	Yes
Posted speed	25 mph
Sensor positions	NS
Number of sensors	2
Sensor types	NS
Types of treatments	DSFS
Number of relevant sites	3
Number of cases	3
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	2 years
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[2]	NS

[2] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

1.3. Summary of Study

The Addison Country Regional Planning Commission evaluated the effectiveness of a DSFS in rural Vermont on local roads with pedestrian activity. The commission measured changes in speed due to two DSFS signs at three locations along Harbor Road in Shelburne, Vermont. The posted speed limit was 25 mph for all three locations. Speeds were measured in 2010, two years before DSFS installation, for an unspecified duration and at unspecified times. Speeds were measured again in 2012, during DSFS installation, for an unspecified duration and at unspecified times. The technology for collecting speed data was not specified. The exact location of the speed data collection in relation to the DSFS was not specified. The measures of effectiveness were mean speed, 85th percentile speed, and 10 mph pace speed.

Data reported. The study reported mean speeds, 85th percentile speeds, and 10 mph pace speeds for the before and during periods.

Results. The study reported decreases in speeds, but did not report whether or not the results were statistically significant.

Statistical Analysis. No description provided.

1.4. Study Schematic

Image courtesy of the authors.

1.5. DSFS Graphic

Image courtesy of the authors.

2. City of Bellevue Transportation Department, 2009

2.1. Study Characteristics

Item	Response
Authors	City of Bellevue Transportation Department
Title	Stationary Radar Sign Program: 2009 Report
Publication year	2009

2.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O-O
Safety focus	Multiple
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Multiple
Area type (location)	Urban
Sidewalks present	Multiple
Posted speed	25-35 mph
Sensor positions	Adjacent (NS)
Number of sensors	NS
Sensor types	NS
Types of treatments	DSFS
Number of relevant sites	31
Number of cases	31
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	1-30 months
Duration of activation	Multiple
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[3]	1 month to 8 years

[3] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

2.3. Summary of Study

DSFSs were installed at 31 sites in Washington State. The DSFS were from four different companies: 3M, MPH, Vcalm, and SpeedCheck. All displayed the motorist speed; some flash the speed if it is high enough over the speed limit; some also flash a strobe light. The context was unspecified, but mostly suburban based on the roadway pictures. The roadway type was as follows: Clear line of sight to DSFS was required, roads may be straight or curved, collector or arterial, and have only one lane of traffic facing the sign. Most roads were two-way roads; all appeared to be paved. The posted speeds were 25 to 35 mph. Measures were taken of the mean speed, the 85th percentile speed, and total traffic volume; however, only 85th percentile speed was provided in the paper. The location and type of sensors was unspecified. The measures were gathered before and during the time that the DSFS was activated. All measurements were taken at various times from 2000 to 2009, but there was no consistent duration between before measurements, installation, and during measurements. Data were not averaged across the sites, but were analyzed in aggregate. Independent variables were as follows: treatment, DSFS type, time since installation, location, number of lanes, and posted speed limit. Dependent variables were as follows: mean speed, 85th percentile speed, traffic volume, and crashes. The major hypothesis was H1B. The measure of effectiveness discussed was 85th percentile speed, specifically the percent reduction in speed, with site results available individually and bucketed into four groups: (1) speed increase (2) 0 to 4 percent reduction (3) 5 to 9 percent reduction and (4) 10+ percent reduction. The publication indicates that mean speed was also recorded, but those results are not discussed in this paper.

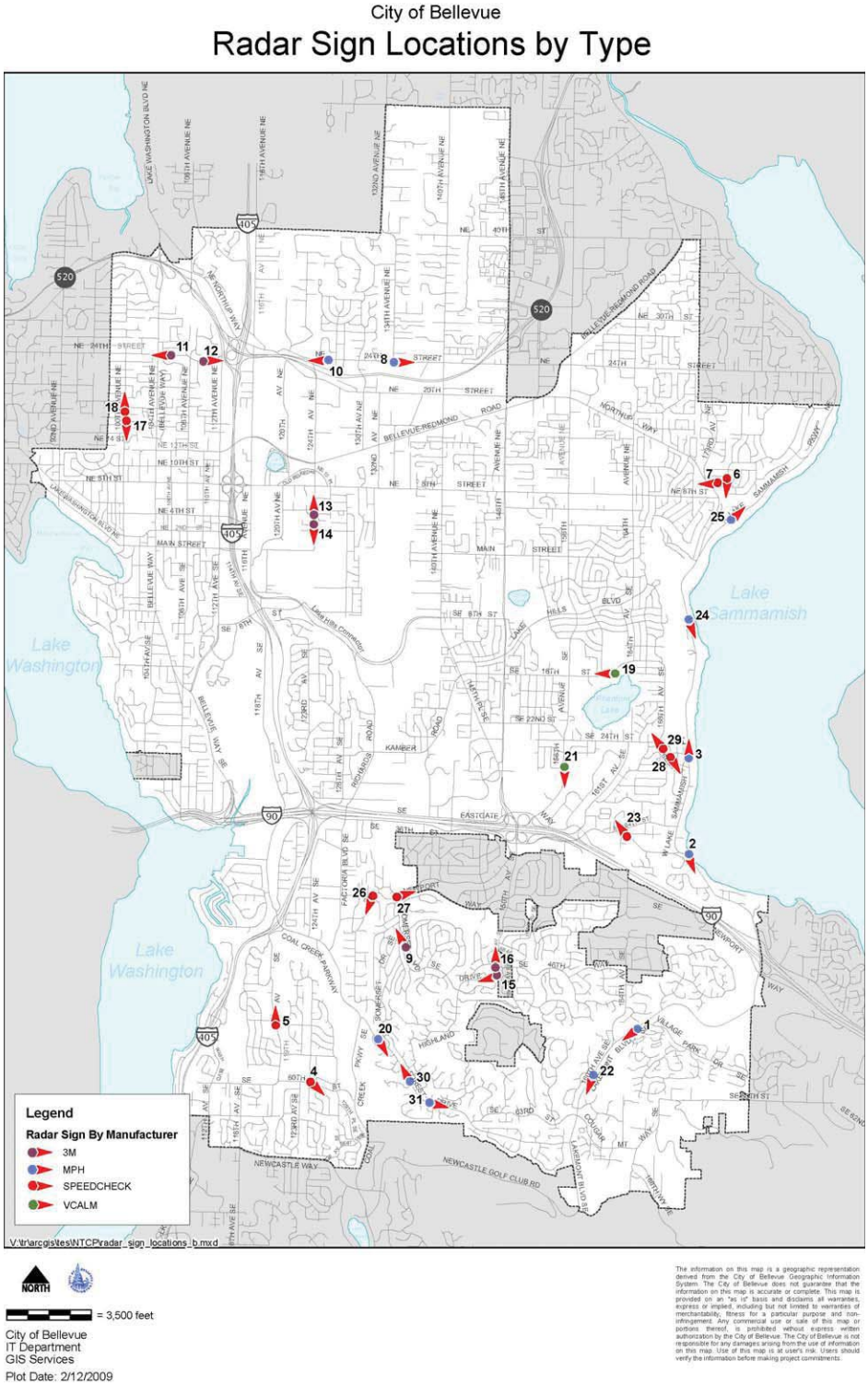
Data Reported. The only data specifically reported were 85th percentile speeds, for all observation sets.

Results. For H1B, the 85th percentile speed decreased at most sites (97%) in the 1 to 3 years following installation, and at all sites in the 2 to 8 years following installation. Effectiveness generally improved over time, with the highest percent of sites finding a 10+ percent reduction in speed 6 to 8 years after installation. However, the number of sites with data available decreases as time since installation increases. On top of the fact that no statistical analysis is discussed, it is difficult to say whether these results are statistically significant.

Statistical Analysis. There was no statistical analysis discussed

2.4. Study Schematic

Image courtesy of the authors.



2.5. DSFS Graphic

There is a picture available of the specific DSFS installed at each of the 31 sites. There are many small variations in style. A few examples (images are courtesy of the authors):

Facing West for Eastbound Motorists

Facing West for Eastbound Motorists

Facing North for Southbound Motorists

Facing North for Southbound Motorists

3. Bertini, Monsere, Nolan, Bosa, and Abou El-Seoud, 2006

3.1. Study Characteristics

Item	Response
Authors	Bertini, Monsere, Nolan, Bosa, and Abou El-Seoud
Title	Field Evaluation of the Myrtle Creek Advance Curve Warning System
Publication year	2006

3.2. Study Features

Feature	Study Information
Experimental design	O-X
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	Southbound: A,B Northbound: B
Hypothesis 2 (H2) level	Southbound: A,B Northbound: B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	Significant reduction recorded

Feature	Study Information
H3: Mean speed	NA
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Arterial
Area type (location)	Rural
Sidewalks present	No
Posted speed	50 mph
Sensor positions	NS, but observations were binned in 200 ft increments, from -1,100 ft upstream to 1,100 ft downstream
Number of sensors	1
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation ("before" measurements)	11 hours total, collected in three installments spanning three months
Time interval between "before" measurements and activation	6 months
Duration of activation	6 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Off peak

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[4]	6 months
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No, but refers to a companion report with best practice information

3.3. Summary of Study

DSFSs were installed at two sites in Oregon. The style of DSFS was an overhead LED sign installed on existing sign bridges. The context was rural. The roadway type was as follows: curved interstate (two travel lanes in each direction) tightly constrained by an embankment on one side and a river on the other. The posted speeds were 50 mph (regulatory) and 45 mph (advised) in the vicinity of the curve. Measures were taken of the mean speed and the speed distribution. For southbound traffic, data were collected from a vehicle parked in the ramp gore area. This location was less than ideal because it was clearly visible to approaching traffic and has been used by Oregon State Police for enforcement purposes. For northbound traffic, data were collected from behind the concrete barrier approximately 420 feet downstream from the sign. Some data were also collected at a location 114 feet upstream of the sign. For each speed observation, the distance was also recorded. This distance was subsequently adjusted to reflect the actual distance of the vehicle upstream or downstream of the dynamic sign system. The speed observations were then binned in 200 ft increments, beginning as far as 1,100 ft upstream and extending as far as 1,100 ft downstream.. The measures were gathered before and during the time that the DSFS was activated. The "before" set of measurements were taken on four separate occasions from October to December; the "during" measurements were taken on three separate occasions the following May and July. Data were not averaged across the sites. Independent variables were as follows: Treatment, distance from DSFS, and vehicle type (passenger or commercial). The measures of effectiveness (dependent variables) were mean speed and speed distribution. The authors also conducted a qualitative survey to obtain driver opinions.

Data Reported. Sample size, mean speed, standard deviation, statistical significance of observed differences, speed distributions, and qualitative survey results.

[4] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Results. The system was effective in reducing the mean speeds of passenger cars and trucks by approximately 3 mph for the southbound direction and 2 mph for the northbound direction.

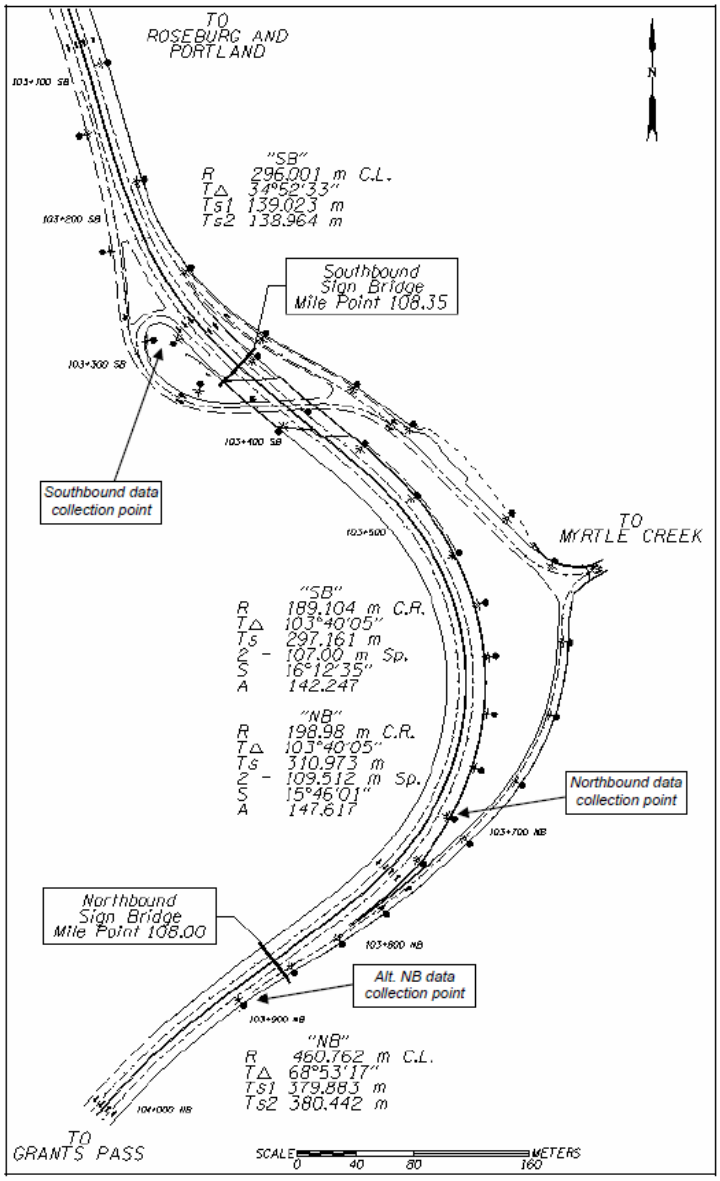
SOUTHBOUND CURVE: For the farthest upstream zones, the before and during mean speeds are not statistically significantly different, as indicated by t-tests in zone −1,100 ft, −900 ft, and −700 ft in Table 6.1 for passenger cars. As drivers approached the sign, however, there was a statistically significant reduction in the mean speeds that appears to be associated with the presence of the system (because the before speeds are similar when the sign is not visible). For commercial vehicles, the same speed trend is evident; however, the results are not as conclusive statistically. Only in the −1,100 and −300 zone are the differences in speeds not significant. After the sign, starting in zone −100, all of the differences are statistically significant. The maximum mean speed reduction occurred in the zone immediately following the sign location and is 3.3 mph for passenger cars and 3.0 mph for commercial vehicles. Just before the curve, passenger vehicles were traveling 56.1 mph before the DSFS was activated and 53.7 mph when the DSFS was activated. Commercial vehicles were traveling 49.7 mph before the DSFS was activated and 48.9 mph when the DSFS was activated.

NORTHBOUND CURVE: The plots in Figure 6.2 for the northbound curve also display reductions in the mean speeds during implementation, but the clear driver reaction to the sign observed in the southbound direction is not evident. The during speeds are statistically significantly lower in all zones except two (−700 commercial vehicles, and 700 commercial vehicles) making it difficult to conclude that speed reductions are attributable only to the dynamic system. Part of the difficulty is related to the availability of data. Unlike the southbound direction, the data collection point was downstream of the system, and as a result, data points in advance of the sign were not as easy to collect. For example, in the −700 zone, only 21 before and 10 during samples were collected. However, the data in Figure 6.2 show speed reductions during the deployment. There were maximum speed reductions of 2.6 mph for passenger cars and 1.9 mph for commercial vehicles. This is consistent with the southbound direction. Just before the curve, passenger vehicles were traveling 54.9 mph before the DSFS was activated and 51.6 mph when the DSFS was activated. Commercial vehicles were traveling 49.4 mph before the DSFS was activated and 46.4 mph when the DSFS was activated. After the system was installed, the distribution of vehicle speeds was statistically different for the different directions, with a lower number of vehicles in the higher speed bins for southbound and northbound passenger and commercial vehicles.

Statistical Analysis. The equality of means for the speeds of each vehicle class for each zone was tested using the t-test for significance. Results of the test are displayed in Table 6.1. The chi-square test indicated that all of the speed distribution shifts were statistically significant at a 95th percent confidence level.

3.4. Study Schematic

Images are courtesy of the Oregon Department of Transportation.


TO
ROSEBURG AND
PORTLAND
N
103+100 SB
"SB"
R 296.001 m C.L.
T△ 34°52'33"
Ts1 139.023 m
Ts2 138.964 m
103+200 SB
Southbound
Sign Bridge
Mile Point 108.35
103+300 SB
103+400 SB
Southbound data
collection point
103+500
TO
MYRTLE CREEK
"SB"
R 189.104 m C.R.
T△ 103°40'05"
Ts 297.161 m
L - 107.00 m Sp.
S 16°12'35"
A 142.247
"NB"
R 198.98 m C.R.
T△ 103°40'05"
Ts 310.973 m
L - 109.512 m Sp.
S 15°46'01"
A 147.617
Northbound data
collection point
103+700 NB
Northbound
Sign Bridge
Mile Point 108.00
103+800 NB
Alt. NB data
collection point
103+900 NB
"NB"
R 460.762 m C.L.
T△ 68°53'17"
Ts1 379.883 m
Ts2 380.442 m
104+000 NB
TO
GRANTS PASS
SCALE
0
40
80
160
METERS

3.5. DSFS Graphic

Images are courtesy of the Oregon Department of Transportation.

Northbound sign bridge, I-5 Milepost 108.00, before and after ACWS installation

Possible advisory messages for DMS

Panel	**Default Message** *Detected Vehicle Speeds Less than 50 mph*	**Warning Message** *Detected Vehicle Speeds 50 to 70 mph*	**Excessive Speed Message** *Detected Vehicle Speeds over 70 mph*
1	CAUTION	SLOW DOWN	SLOW DOWN
2	SHARP CURVES AHEAD	YOUR SPEED IS XX MPH	YOUR SPEED IS OVER 70 MPH

4. Bloch and Automobile Club of Southern California, 2007

4.1. Study Characteristics

Item	Response
Authors	Bloch and Automobile Club of Southern California
Title	Comparative Study of Speed Reduction Effects of Photo-Radar and Speed Display Boards
Publication year	2007

4.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Straight section
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	No change

Feature	Study Information
H3: 85th percentile speed	na
H3: Percentage of drivers over speed limit	No change
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Collector
Area type (location)	Urban
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Adjacent (0 ft); downstream (1050 ft)
Number of sensors	0,1,1
Sensor types	Radar
Types of treatments	DSFS + police
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation ("before" measurements)	2 weeks
Time interval between "before" measurements and activation	NS
Duration of activation	1 week
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[5]	1 week

[5] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	3 hours and 1 week after
Duration of "after" measurements	NS
Meta-analysis data available	No
Caveats	None
Best practices information available	Yes

4.3. Summary of Study

DSFSs were installed at two sites in Riverside, California. The DSFS were speed display boards (SPECTER Trailers equipped with a traffic radar unit, a solar power cell, and a large (0.3 meter) numerical display). The context was urban. The sites were residential collector roads, 11 to 12 meters wide, with one lane in either direction, with no stop signs or traffic signals, with a traffic volume of 800 to 2,400 vehicles per day per lane. The posted speeds were 25 mph. There were two relevant treatment conditions: One site had a speed display board (unenforced) and the other site had a speed display board accompanied by intermittent police enforcement. These measures were taken adjacent to the speed display board and 320 meters downstream. The measures were gathered before installing and activating the speed display boards, and during their activation. Data were not averaged across sites. Independent variables were as follows: Measurement location, treatment condition. The measures of effectiveness (dependent variables) were mean speed and percent of vehicles 10 mph above the speed limit.

Data Reported. Mean speed and percent of vehicles 10 mph above the speed limit.

Results. Speed display boards reduced mean speeds by 9.3 kph (5.78 mph) at the display board location. They reduced mean speeds by 4.7 kph (2.93 mph) at a location 320 meters downstream. Speed display boards become statistically significantly more effective when supplemented with police enforcement, but only downstream; the site with supplemental police enforcement showed a reduction of 9.8 kph (6.08 mph) at the speed display board and a reduction of 9.5 kph (5.90 mph) 320 meters downstream. Reductions in "excessive speeds" (traveling 16 kph (10 mph) or more over the legal limit) were greater than mean speed reductions, both at the speed display board and downstream. The observed deactivation effects were different for the enforced versus unenforced speed display boards. The former (enforced) showed significant lingering short term effects (3 hours) but no significant long-term effects (1 week) as compared to the before condition, at the DSFS as well as downstream. The latter (unenforced) did not have any available data on short term effects (3 hours), as the study did not collect this data, but data did show a significant lingering effect (1 week) at the DSFS (not downstream).

Statistical Analysis. Statistical analysis not described. However, the paper indicates whether observed differences were statistically significant, so the implication is that the authors conducted statistical testing.

4.4. Study Schematic

None provided.

4.5. DSFS Graphic

None provided.

5. Bowie, 2003

5.1. Study Characteristics

Item	Response
Author	Bowie
Title	Efficacy of Speed Monitoring Displays in Increasing Speed Limit Compliance in Highway Work zones
Publication year	2003

5.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	Multiple
Sensor positions	Upstream (varied at each site), adjacent (NS), downstream (varied at each site)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS and DSFS + police
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation ("before" measurements)	Multiple
Time interval between "before" measurements and activation	Multiple
Duration of activation	Multiple
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[6]	Multiple

[6] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

5.3. Summary of Study

This study evaluated the effectiveness of two strategies for reducing speeds in highway work zones. The first strategy was a DSFS and the second treatment was the presence of a police vehicle. Specifically, the treatment conditions applied were: one or more DSFSs, a stationary police vehicle with radar on, a stationary police vehicle without radar on, a cruising police vehicle, and a combination of the DSFS and each of the police treatments. These were tested at seven highway work zone locations in Utah during the summer and fall of 2002. Speeds and vehicle types were recorded using pneumatic tubes and data recorders.

Although a variety of sites were tested, only two were statistically analyzed (I-80 West and I-15 South). The other sites had various issues that compromised the quality and/or quantity of the data.

- I-80 West: Only one lane was open to traffic at this site. Due to the wide shoulder the speed limit was not lowered in the work zone from the normal 65 mph. Data collection began around 1 a.m. on a Tuesday in September. At 2:30 a.m., the state trooper arrived and turned on his radar and roof lamp. The DSFS was turned on at the same time. Starting at 3:30 a.m. the trooper turned off the radar, but kept the roof lamp on. The DSFS remained on the entire time. Data collection ended at about 4:15 a.m. It was noted that drivers voluntarily significantly slowed down near the workers because the workers were very close to the open lane.
- I-15 South: Researchers noted that this site was ideal for data collection because vehicles were forced to travel in one lane for a long distance with no on- or off-ramps, data could be collected over several weeks and with several different conditions, and drivers were

primarily non-commuters. Data were collected over a 3-week period. At various times throughout that 3-week period, the site had no treatment, DSFS, police, or a combination of both. Data were collected and categorized accordingly. The normal speed limit in the study area is 75 mph, but it was decreased to 55 mph in the work zone. The change occurred entirely upstream of the study site.

For each study site, a minimum of three data collectors were used. In each case, the first data collector was set up in the work zone but before the treatment could be detected by the driver. The second data collector was set up near where the treatment was applied (except in the case of a cruising police vehicle, where this was impossible). The final data collector was located in the work zone, usually near the end of the work zone. Where the work zone was long enough, as many as seven data collectors were set up to collect data throughout the entire study area. The measure of effectiveness was mean speed. The DSFS was orange, with a character board display 22.75 inches wide and 16.5 inches high. The hypotheses investigated were H1B and H2B.

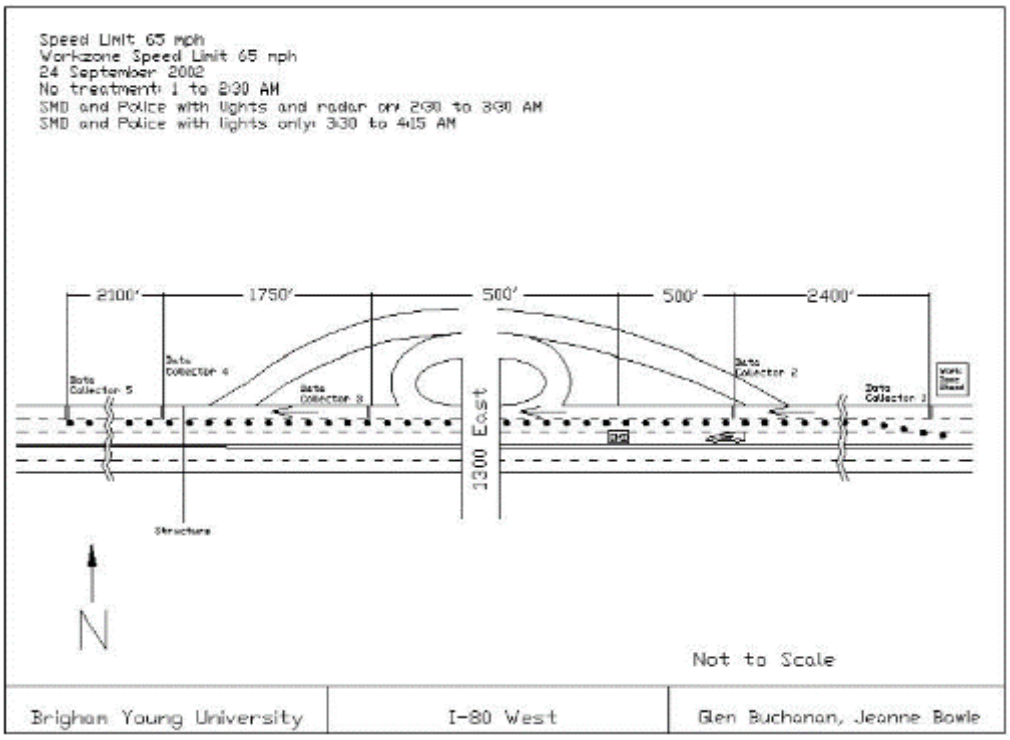
Data reported. Sample size, mean speed, standard deviation.

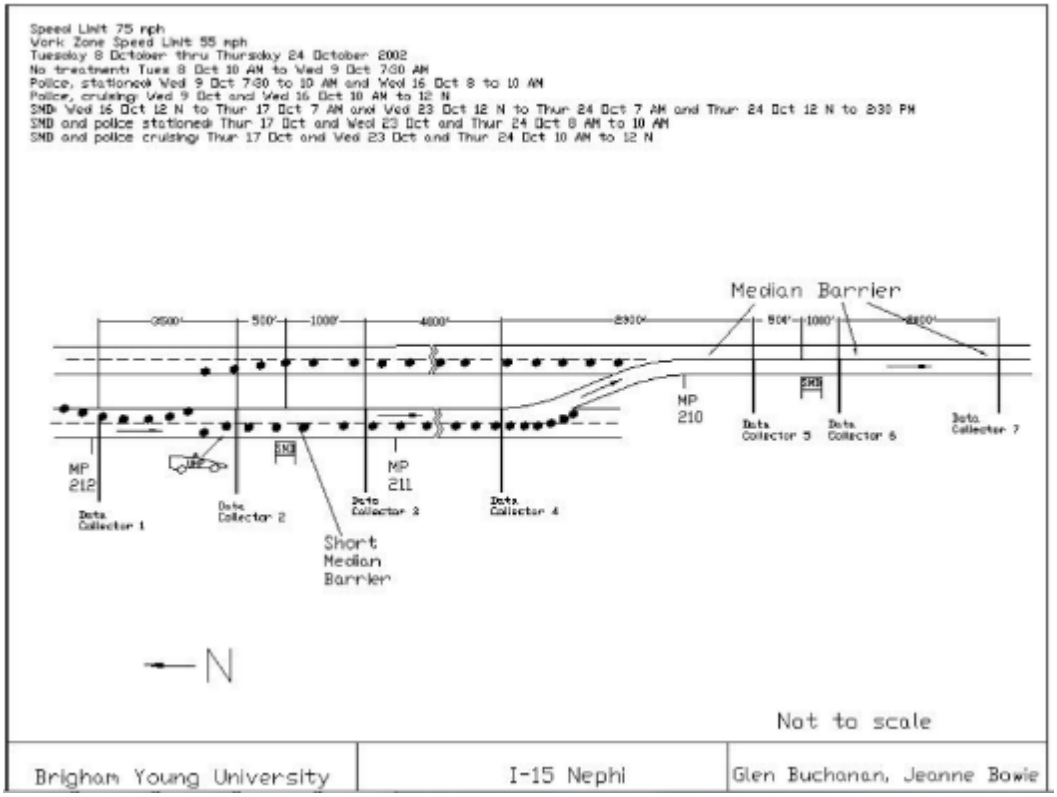
Results. Statistically significant at a 95% confidence level, the study found that: in the no-treatment case, mean speed was reduced about 3 mph as vehicles entered the work area of the work zone. With the DSFS, mean vehicle speed was reduced an additional 4 mph. With the police vehicle, mean vehicle speed was reduced about 6 mph more than in the no-treatment case.

Statistical Analysis. "The statistical analysis was performed using the data from only three data collectors at each site: the initial data collector (where the treatment had not yet been applied), the data collector directly following any treatment that was applied, and one of the final data collectors. Compiled data were analyzed using general linear models to determine if there were statistically significant differences between the treatments."

5.4. Study Schematic

Images are courtesy of the authors.





5.5. DSFS Graphic

Images are courtesy of the authors.

6. Brewer, Pesti, and Schneider, 2006

6.1. Study Characteristics

Item	Response
Authors	Brewer, Pesti, and Schneider
Title	Improving Compliance With Work zone Speed Limits
Publication year	2006

6.2. Study Features

Feature	Study Information
Experimental design	O–X–O–X–O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	B
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	No change

Feature	Study Information
H3: Percentage of drivers over speed limit	No change
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Arterial
Area type (location)	Rural
Sidewalks present	No
Posted speed	Multiple
Sensor positions	Upstream (-1 mile); at DSFS(0 ft); downstream (unclear)
Number of sensors	1,1,3
Sensor types	Pneumatic
Types of treatments	DSFS (portable changeable message sign with speed feedback and speed display trailer)
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	3 days
Time interval between "before" measurements and activation	3 days
Duration of activation	1 week
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[7]	1 week

[7] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NS
Duration of "after" measurements	NS
Meta-analysis data available	Yes
Caveats	Only graphical. No sample size or standard deviation.
Best practices information available	Yes

6.3. Summary of Study

DSFSs were installed at two sites in Texas. The context was rural. This involved portable changeable message signs with radar (PCMRs), speed display trailers (SDTs), and orange border speed limit signs (OBSLS) installed in varying combinations over time. The roadway type was as follows. Site 1: Interstate highway, where two-way traffic was carried on the two reconstructed westbound lanes while the two existing eastbound lanes were removed and rebuilt. Site 2: Four-lane divided highway, where all lanes remained open to traffic during construction. The posted speeds were as follows. Site 1: 70 mph at the first measurement, then 60 mph. Site 2: 70 mph at the first measurement, then 55 mph. Measures were taken of the 85th percentile speed, standard deviation of speed, and the percentage of vehicles complying with the speed limit. These measures were taken 1 mile upstream of the DSFS, at a second location at an unspecified distance upstream of the DSFS, at the DSFS, and at two other locations at an unspecified distance downstream of the DSFS. At Site 1, measures were gathered 3 days before activation at all six sensors (Before PCMR condition). One PCMR (PCMR1) was installed for 10 days at the merge taper downstream of the first advance warning sign (sensor location 2) and measures were gathered for the last 3 days at all six sensors (PCMR1 condition). PCMR1 was removed for 3 days and data were collected (After PCMR1 condition). PCMR1 was reinstalled at the merge taper (downstream of sensor location 2) along with another PMCR (PMCR2) that was installed further downstream near the midpoint of the work zone (downstream of sensor location 3). The installation was again for 10 days and measures were gathered during the last 3 days at all six sensors (PCMR1+PCMR2 condition). Finally, both PMCRs were removed and OBSLSs were installed for 10 days, one upstream of the merge taper and one near the midpoint of the work zone (OBSLS condition). Measures were gathered at all six sensors for last 3 days of the 10 day installation. At Site 2, the procedure was very similar. Data were measured before activation (Before SDT condition). The SDT was installed at the beginning of the work zone (downstream of Location 2) for 10 days and measures were taken during the last 3 days (SDT condition). The SDT was removed for 3 days and data were collected (After SDT condition). Finally, the OBSLSs were installed at the beginning of the work zone and data were collected (OBSLS condition). Each site had a different treatment, so data were not averaged across the sites. Independent variables were as follows: Vehicle type (truck/car), measurement location (six locations at Site 1; five at Site 2), and treatment condition (four for Site 1; three for Site 2). Dependent variables were as follows: 85th percentile speed, standard deviation of speed, and the

percentage of vehicles complying with the speed limit at each of the six different sensor locations. The major hypotheses were H1, H2A, H3A, and H3B. The measures of effectiveness used in the evaluation of the speed control devices included 85th percentile speed, standard deviation of speed, and percentage of vehicles complying with the speed limit.

Data Reported. The 85th percentile speeds and percentage of drivers exceeding the speed limit are reported at all sensor locations for Sites 1 and 2 across all conditions for each site. Pairwise comparisions were reported for the dependent variables at selected sensor locations between selected conditions. The type of statistical test used to evaluate the pairwise comparisons was not reported.

Results. H1: Activation Effect at DSFS. At Site 1 in condition PCMR1, there were statistically significant reductions in the 85th percentile speed of vehicles at Location 3 (2 mph, immediately downstream of PCMR1) and of trucks at Location 3 (1 mph). Additionally, the percentage of vehicles and trucks exceeding the speed limit at Location 3 (immediately downstream of PCMR1) increased during activation to 32 percent from 21 percent before activation (significant). At Site 2 in condition SDT, there were stastically significant reductions in the 85th percential speed of vehicles at Location 2 (4 mph, immediately downstream of the SDT) and of trucks at Location 2 (4 mph). Additionally, the percentage of vehicles and trucks exceedinng the speed limit at Location 2 (immediately downstream of PCMR1) increased during activation to 54 percent from 31 percent before activation (significant). H2: Activation Effect on Downstream Sensor. At Site 1 the PCMR reduced 85th percentile speeds for both passenger cars (1 mph) and trucks (1 mph) at Location 4, the measurement location that is the next one downstream of the measured location nearest the PCMR (both reductions were significant). The percentage of vehicles complying with the speed limit was higher at Location 4 when the PCMR was activated (44%) than before it was activated (34%) (signficiant). At Site 2, the SDT reduced the 85th percentile speeds for both passenger cars (2 mph) and trucks (2 mph) at Location 3, the measurement location that is the next one downstream of the measured location nearest the SDT (the significance was not reported). The percentage of vehicles complying with the speed limit was higher at Location 3 when the SDT was activated (45%) than before it was activated (41%) (significant). H3A: Deactivation Effect at DSFS. At Site 1 the PCMR at Location 3 did not have a significant residual effect on 85th percentile speeds. At Site 2 the SDT at Location 2 actually increased the 85th percentile speeds after the device was removed. At both sites, the percent of drivers in compliance with the speed limit declined after the DSFS was removed, to a percentage below the "before" value, significant at the 95% confidence level. A multifactor analysis of variance determined that vehicle type, speed measurement location, and treatment all had statistically significant effects on vehicle speeds at both sites at the 95% confidence level. The study did not report any results for mean speeds, even though that was one of stated measures.

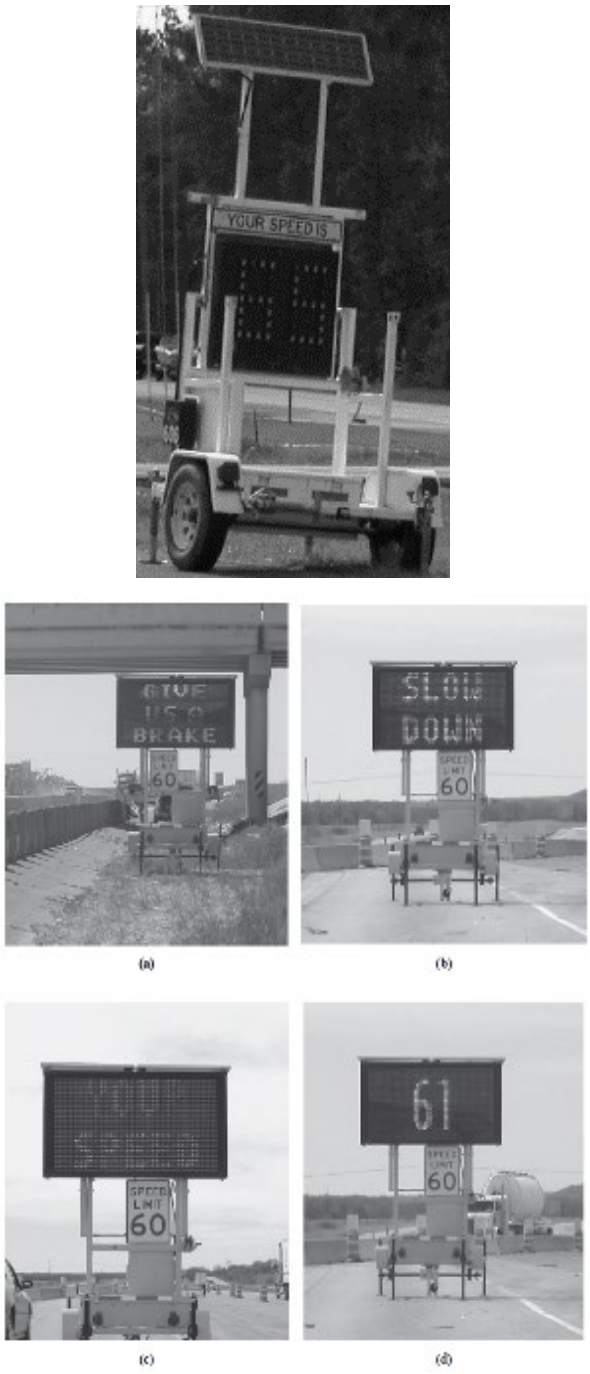
Statistical Analysis. "A multifactor analysis of variance was performed to determine which factors have a statistically significant effect on vehicle speed. Factors considered included vehicle type, speed measurement location, and treatment. All significance tests were conducted at the 95% confidence level. The statistical significance of the differences in the mean speeds was determined with t-tests. The differences in 85th percentile speeds were tested for statistical significance through a post hoc quantile test using a nonparametric bootstrapping procedure. Binomial proportion tests were used to evaluate the statistical significance of differences in percentages of vehicles complying with the speed limit. Also, F-tests were used to check for statistically significant differences in the standard deviations of speeds."

6.4. Study Schematic

Not provided.

6.5. DSFS Graphic

Images are courtesy of the authors and reproduced with permission of the Transportation Research Board.



Messages on portable changeable message signs with radar: (a) default PCMR message, (b) first phase for violators, (c) second phase for violators, and (d) final phase for violators

7. Bullough, Skinner, Brons, and Rea, 2012

7.1. Study Characteristics

Item	Response
Authors	Bullough, Skinner, Brons, and Rea
Title	Using Lighting and Visual Information to Alter Driver Behavior
Publication year	2012

7.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	No
DSFS speed lighting	Yes
DSFS flashes (speed or other)	No
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Suburban
Sidewalks present	No
Posted speed	30 mph
Sensor positions	Adjacent (328 ft)
Number of sensors	0,1,0
Sensor types	Radar
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	5 hours
Time interval between "before" measurements and activation	NS
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Off peak
Time intervals at which measurements were taken during activation ("during" measurements)[8]	NS

[8] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

7.3. Summary of Study

This study examined the effectiveness of two safety countermeasures. Relevant to this literature review, it evaluated a sign with conditional messages based on driver speed. Initial tests were conducted in controlled field experiments and then follow-up evaluations studied the effectiveness in real-world conditions. The real-world test location for the sign was located along Jordan Road, a small local road in the Rensselaer Technology Park in North Greenbush, New York. The sign was located on the grass adjacent to the road, and no construction work or other activity took place in the road itself during the data collection.

The light-emitting diode sign was programmed to display several conditional messages based on the speed of the approaching vehicle:

- If a vehicle is going faster than 30 mph: "REDUCE SPEED TO 25 MPH"
- If a vehicle is going 25 to 30 mph: "25 MPH SPEED ZONE"
- If a vehicle is going 20 to 25 mph: (No Message)
- If a vehicle is going less than 20 mph: "25 MPH SPEED ZONE"
- When no vehicles are approaching the sign it rests in a blank display.

Although the original speed limit along this road segment was 30 mph, the speed display sign was set up to encourage driving speeds of 25 mph. Approximately 328 ft. downstream from the display a member of the project team hid among several trees and an electrical junction box and measured speeds with a radar gun. Further downstream a sign alerted drivers that the speed limit reverted back to 30 mph. All measurements were taken in clear weather in the middle of the day to avoid peak rush hour. If vehicles were closely spaced, only the speed of the lead vehicle was measured to ensure independent speed measurements.

Data were collected before and during sign implementation, but the publication did not specify how much time elapsed between the measurements:

- Before: From 10 a.m. to 3 p.m., a total of 663 vehicle speeds were measured.
- During: From approximately 9:45 a.m. to 11 a.m., speeds for 108 vehicles were measured.

The measures of effectiveness were mean speed and the standard deviation of speed. The hypotheses investigated were H1B and H2B.

Data reported. Mean speeds and standard deviation, as well as histograms of speed observations.

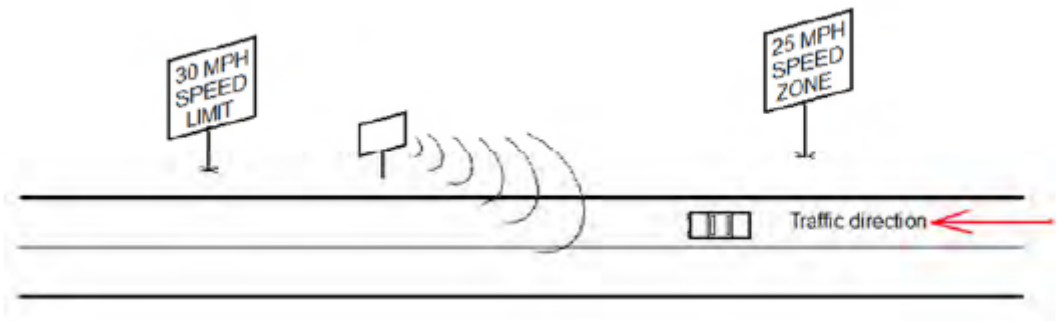
Results. There was a statistically significant ($p<0.001$) reduction in the mean measured speeds during the installation test compared to the baseline conditions. The speed display messaging appeared to have the intended effect of reducing speeds closer to 25 mph (from a mean of 30 mph and a median of 33 mph), and also reduced the standard deviation of the measured speeds from 7.88 to 4.66 mph.

Statistical Analysis. The publication did not describe the statistical analysis, but it did report that results were statistically significant, implying that the researchers conducted statistical analysis.

7.4. Study Schematic

Images are courtesy of the authors.

Aerial view and map of the test location. The yellow area indicates the portion of Jordan Road that was used for the test.



Schematic layout of speed display installation

7.5. DSFS Graphic

Image courtesy of the authors.

Speed display shown in response to speeds greater than 30 mph.

8. Chang, Nolan, and Nihan, 2004

8.1. Study Characteristics

Item	Response
Authors	Chang, Nolan, and Nihan
Title	Radar Speed Signs on Neighborhood Streets: An Effective Traffic Calming Device?
Publication year	2004

8.2. Study Features

Feature	Study Information
Experimental design	O-O-O-X-O-O-O
Safety focus	Straight section
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	NS
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Collector
Area type (location)	Urban
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Adjacent (0 ft)
Number of sensors	0,1,0
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	4
Number of cases	4
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	15 months, 4 months, and 1 week
Duration of activation	22 months
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[9]	1, 7, and 22 months

[9] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	No
Best practices information available	No

8.3. Summary of Study

DSFSs were installed on both sides of a straight 2-lane minor (collector) arterial with long sight lines and "some vertical sight distance concerns" in the state of Washington. The site, 108th Avenue NE, was urban. There are 10+ local streets intersecting the roadway, which sees average daily traffic volumes of 2,700 on the north end and 4,900 on the south end. The roadway is ~1,400 yards (.8 miles) long, terminating at intersecting roads on both ends. The entire roadway has a posted speed limit of 25 mph. Defining Location 1 as that of the first sensor and setting it at 0 feet, Locations 2, 3 and 4 for the second, third and fourth sensors heading northbound were at 900 feet, 2,500 feet and 3,300 feet. The independent variables were the side of the roadway (northbound or southbound) and the time of measurement -- three times before activation (April 2001, Feburary and early June 2002) and four times after activation (late June and August 2002, January 2003, April 2004). Measures were taken of the mean speed and 85th percentile speed at two locations north bound and two locations southbound. Two DSFSs were installed on the northbound side and two on the southbound side. On the northbound side, the first DSFF was located at approximately 400 feet and the second DSFS was located at approximately 2,600 feet. On the southbound side, the first DSFS encountered was located at approximately 3,200 feet and the second DSFS was located at approximately 1,300 feet. The measures were gathered before (~1 week, 4 months, 15 months) and during (~1 week, 2 months, 7 months, 22 months) the time that the DSFS was activated. There were no measurements after the DSFS was removed. For the northbound side, the measures were taken at Location 1 (400 upstream of the first northbound DSFS) and Location 3 (2,100 feet downstream of the first DSFS and 100 feet before the second northbound DSFS). For the southbound side, the measures were taken at Location 4 (200 feet upstream of the first southbound DSFS) and Location 2 (1,600 feet downstream of the first southbound DSFS and 400 feet downstream of the second DSFS). The major hypothesis was H1B.

Data Reported. Data were reported for each of the two locations on the northbound and southbound sides at each point in time before and during the activation for both dependent variables. Additionally, the traffic volume and standard deviation were reported for the before and during periods. Finally, the mean speed at all four locations along with the sample size and standard deviation were reported.

Results. The mean speed was averaged over the three before periods and the four during periods and compared using a *z* test. At three of the four locations (one northbound and two southbound), the change was statistically significant. These sites showed a decrease in mean speed of 1.19 to 2.21 mph. The fourth site showed a statistically significant increase in mean speed, of .51 mph. There was a statistically significant ($p<.05$) decrease in volume at one site. The authors did not report a similar analysis of the 85th percentile speeds, but one can easily obtain descriptive statistics. At the near and far downstream northbound sensor locations, the reductions in 85th percentile speed were respectively -1.90 and -1.30 mph. In the near and far downstream southbound sensor locations, the reductions in speed were respectively -1.60 and -1.00 mph.

Statistical Analysis. The researchers determined whether observed differences were statistically significant at the 0.05 level of significance.

8.4. Study Schematic

Not provided.

8.5. DSFS Graphic

Not provided.

9. Cruzado and Donnell, 2009

9.1. Study Characteristics

Item	Response
Authors	Cruzado
Title	Evaluating Effectiveness of Dynamic Speed Display Signs in Transition Zones of Two-Lane, Rural Highways in Pennsylvania
Publication year	2009

9.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars
Hypothesis 1 (H1) level	A
Hypothesis 2 (H2) level	C'
Hypothesis 3 (H3) level	A'
H1: Mean speed	Significant reduction recorded after 1 week. Nothing reported for the 2 sites at 2 weeks.
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported

Feature	Study Information
H3: Mean speed	Significant increase recorded. Nothing reported for the 2 sites at 2 weeks.
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Arterial
Area type (location)	Rural
Sidewalks present	NS
Posted speed	45-55 mph before transition; 25-35 mph after transition; reductions could be as much as 20 mph and as little as 15 mph
Sensor positions	Upstream (-0.5 mile); adjacent (0 ft); downstream (500 ft)
Number of sensors	1,1,1
Sensor types	Other
Types of treatments	DSFS
Number of relevant sites	12
Number of cases	12
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	1 week for 10 of the sites and 2 weeks for 2 of the sites
Time of day when speed is measured (a.m./p.m.)	Weekdays
Time of day when speed is measured (peak/off peak)	Off peak

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[10]	1 week
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	0
Duration of "after" measurements	1 week
Meta-analysis data available	Yes
Caveats	No
Best practices information available	No

9.3. Summary of Study

DSFSs were installed at 12 sites in rural Pennsylvania. The sites included both curved and straight sections of roadway where a transition was being made from a two-lane highway to a rural community. The traffic was freely flowing. The posted speed limits of the highway upstream of the transition zone were 45 mph to 55 mph. The posted speed limits in the transition zone were between 25 mph and 35 mph. Measures were taken of the mean speed, the 85th percentile speed, and the percentage of vehicles exceeding the speed limit for 0.5 mile upstream of the DSFS, at the DSFS, and 500 feet downstream of the DSFS (12 sites total). The measures were gathered before (1 week), during (1 and 2 weeks for 2 of the 12 sites) and after (1 and 2 weeks for 2 of the 12 sites) the DSFS was activated. The independent variables included the site (1 of 12) and the time of measurement (before, during, and after activation of the DSFS). The dependent variables included the mean speed, 85th percentile speed, and percentage of vehicles exceeding speed limit. Three major hypotheses were evaluated: H1A, H2C', and H3A'. The mean speeds before, during, and after are reported at each of the 12 sites for the sensors upstream, adjacent, and downstream (and for 2 of the 12 sensors, 2 weeks of during and 2 weeks of after data are reported). Overall information was also reported on the 85th percentile speeds and the percentage of drivers exceeding the speed limit.

Results. *H1A:* There was a statistically significant decrease in the mean speeds at 11 of the 12 sites. The average decrease across all sites was -6.23 mph. *H2C':* At six of the 12 sites, the mean speeds downstream of the DSFS were 1 mph or less (no significance tests reported). No statistical tests were reported. *H3A':* There was a statistically significant increase in the mean speed after deactivation of the DSFS compared to the period when the DSFS was activated. The average increase across all 12 sites was 6.58 mph.

Additional Results. At both the DSFS and the downstream locations, the 85th percentile speeds were lower when the DSFS was activated, but increased to the before period after deactivation.

[10] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

The same pattern was observed for the percentage of vehicles exceeding the speed limit. At 6 of the 12 sites the mean speeds at the downstream sensor differed by less than one mph from the sensor at the DSFS when the DSFS was activated. At the remaining 6 sites the mean speeds were greater than 1 mph at the two sensors.

Statistical Analysis. Two sample t-tests were used to determine whether differences were significant. As best we can tell, for the analysis of the activation effect at the DSFS the authors took the difference for each vehicle between the speed at the upstream sensor and the DSFS sensor and so had one observation for each vehicle before activation and one observation per vehicle during activation. They then evaluated whether the two differences were statistically significantly different from each other using a between-subjects t-test (H1A). They did the same thing for the deactivation effect (H3A').

9.4. Study Schematic

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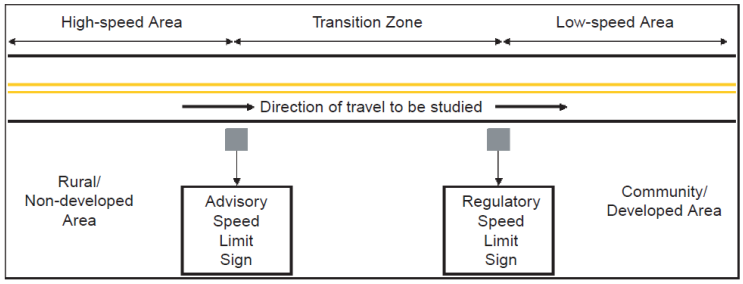


FIGURE 2 Typical transition zone.

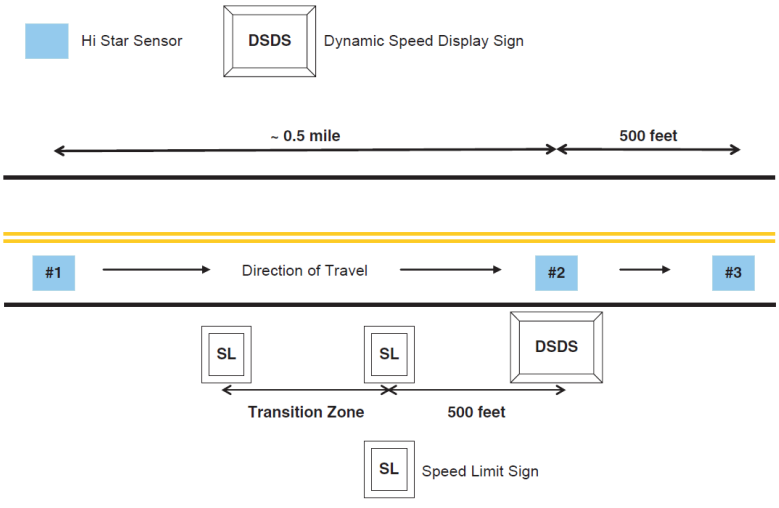


FIGURE 3 Data collection site setup (SL = speed limit sign).

9.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

10. Drakopoulos, Uprety, and Vergou, 2003

10.1. Study Characteristics

Item	Response
Authors	Drakopoulos, Uprety, and Vergou
Title	I-43 Speed Warning Sign Evaluation
Publication year	2003

10.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	A,B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction only for semi-trucks that activated the sign
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	No
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Freeway
Area type (location)	Urban
Sidewalks present	No
Posted speed	50 mph
Sensor positions	Upstream (-515 ft) and downstream (345 ft)
Number of sensors	1,0,1
Sensor types	Multiple (laser and inductive loop)
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	1 week
Time interval between "before" measurements and activation	1 week
Duration of activation	1 week
Time of day when speed is measured (a.m./p.m.)	a.m.
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[11]	Entire duration

[11] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

10.3. Summary of Study

The study evaluated the effectiveness of a DSFS installed on a sign bridge over I-43 in urban Milwaukee County, Wisconsin, 345 feet upstream of a curve (point of curvature). The DSFS relied on system detectors another 515 feet upstream of the DSFS sign. These detectors recorded each vehicle's weight, speed, and vehicle class. If the vehicle exceeded a predetermined threshold for its class (based on weight and speed), the sign would show the message "TOO FAST FOR CURVE" and flash. The speed limit was 50 mph.

Researchers used laser guns to collect speed data at the point of curvature for the curve. Mean speed was the only speed-related measure of effectiveness evaluated in the study. "Before" data were collected over one week. The sign was installed, and then "during" data were collected over one week. Data were collected in the morning during the day, and speeds were recorded 515 feet upstream of the DSFS and 345 feet downstream of the DSFS (at the point of curvature of the curve).

The study evaluated four hypotheses (collectively classified as H2A and H2B, but differentiating between target and non-target populations).

- The speeds of vehicles that activated the sign would decrease downstream of the DSFS.
- The speeds of vehicles that activated the sign would remain the same upstream of the DSFS.
- The speeds of vehicles that did not activate the sign would remain unchanged downstream of the DSFS.
- The speeds of vehicles that did not activate the sign would remain unchanged upstream of the DSFS.

Data reported. Mean speeds, sample sizes, and standard deviations were reported separately for various vehicle types, and for vehicles that activated the sign versus those that did not.

Results. The overall traffic speeds did not show any perceptible change from the "before" to the "during" condition. However, speeds at the point of curvature were lower by 3.2 mph for semi-trucks that activated the sign (statistically significant at the 0.05 level of significance). Speed reductions were also documented for other vehicle types that activated the sign, but these findings were tentative due to small sample sizes.

Statistical Analysis. The researchers determined whether observed differences were statistically significant at the 0.05 level of significance.

10.4. Study Schematic

See *Figure 1* in article

10.5. DSFS Graphic

See *A2 sign face dimension details* in article.

11. City of Englewood, Colorado, 2014

11.1. Study Characteristics

Item	Response
Authors	City of Englewood, Colorado
Title	City of Englewood, CO: Recent Accomplishments
Publication year	2014

11.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Straight section
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	Yes
Posted speed	30 mph
Sensor positions	NS
Number of sensors	1
Sensor types	NS
Types of treatments	DSFS
Number of relevant sites	6
Number of cases	6
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[12]	2 months, 3 years

[12] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	No sample sizes
Best practices information available	No

11.3. Summary of Study

This report summarized the effectiveness of implemented safety measures; one part of this involved DSFS installed at several residential locations. No sample sizes or significance levels were reported. Stationary DSFS were installed at two locations in 2003 (Quincy Avenue and Logan Street) and two locations in 2005 (E. Dartmouth Avenue and Oxford Avenue) All locations had speed limits of 30 mph. The Dartmouth and Oxford locations received signs for both eastbound and westbound traffic, comprising four data sets. Follow up speed studies were conducted in 2006 and found that 85th percentile speeds decreased at all sites. Additionally, mean and 85th percentile speed data is reported for Dartmouth two months after installation and compared to speed data before installation. A DSFS was installed at one additional site, Inca Street, but no results are reported for this location.

Data Reported. The article reported 85th percentile speeds for 6 sites and mean speed for 2 sites (one location, eastbound and westbound). For one site, Inca Street, no data was reported.

Results. The 85th percentile speed results show decreases at all six sites when comparing before and after. No significance is reported. The results from Dartmouth 2 months after installation were inconsistent: the westbound sign found decreases in both mean (33 to 27 mph) and 85th percentile speed (36 to 30mph); the eastbound sign found increases in both (30 to 32 and 34 to 35).

Statistical Analysis. No statistical analysis was discussed.

11.4. Study Schematic

Not provided

11.5. DSFS Graphic

Not reproduced here. See article.

12. Fontaine, 2001

12.1. Study Characteristics

Item	Response
Authors	Fontaine
Title	Evaluation of Speed Displays and Rumble Strips at Rural-Maintenance Work Zones
Publication year	2001

12.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction for trucks at 1/2 sites, insignificant reduction for trucks at 1/2 sites, insignificant reduction for cars at 2/2 sites
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Significant reduction for trucks and cars at 1/2 sites, insignificant reduction for cars at 1/2 sites, No change for trucks at 1/2 sites
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction for trucks at 2/2 sites,significant reduction for cars at 1/2 sites, insignificant reduction for cars at 1/2 site
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	No change for trucks at 2/2 sites, for cars at 1/2 sites; significant decrease for cars at 1/2 sites.

Feature	Study Information
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	Yes
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	70 mph
Sensor positions	Upstream (-3,077 or -1310 ft); adjacent (-321 or -416 ft); downstream (437 or 578 ft and 1,482 or 3,112 ft)
Number of sensors	1, 1, 2
Sensor types	NS
Types of treatments	DSFS
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation ("before" measurements)	Half day
Time interval between "before" measurements and activation	Unclear - 0 hours to half a day
Duration of activation	half day
Time of day when speed is measured (a.m./p.m.)	day
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[13]	NA
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	No sample size or standard deviation, Not possible to calculate effrect size
Best practices information available	No

12.3. Summary of Study

DSFSs were installed at four rural highway work zone sites in Texas. However, only two of these sites involved DSFS treatments (at first no controls were in place, then standard work zone traffic controls, and then the DSFS was installed). The remaining two sites followed the same pattern, but with rumble strips as the last intervention instead of DSFS. The posted speed was 70 mph at all sites. Measures were taken of the mean speed and fraction of drivers exceeding the speed limit. Four sensors collected data at each site: an upstream sensor before the DSFS was visible, a sensor "at" the DSFS (321 or 416 feet upstream, but in sight of the DSFS), a near downstream sensor (578 or 437 feet after the DSFS), and a far downstream sensor (1,482 or 3,112 feet after the DSFS). The far downstream sensor is closest to the work zone, in both cases, and thus is the sensor we use to evaluate H2. Each site additionally had a fifth sensor placed that malfunctioned; one was upstream, one downstream. The measures were gathered before and during the time that the DSFS was activated. There were no measurements after the DSFS was removed. All measurements were taken over the course of a single day, with the DSFS activated around midday. Data were analyzed for each location. All DSFS displayed the speed via LED as well as having a flashing strobe when speeding 5+ mph over the limit. Independent variables were as follows: treatment and vehicle type. Dependent variables were as follows: mean speeds and percentage of the sample exceeding the speed limit. The major hypotheses were H1B and H2B. The article reported mean speeds, percent of drivers exceeding the speed limit, and whether these changes were significant for each sensor location. It did not provide sample size, variance, or standard deviation.

Results. For H1, mean speed dropped significantly for trucks at one site, by 9.4 mph. Mean speed dropped insignificantly for trucks at the other site, and dropped insignificantly for cars at both sites. For H2, mean speed dropped significantly for trucks at both sites, by 7.1 and 9.9 mph.

[13] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

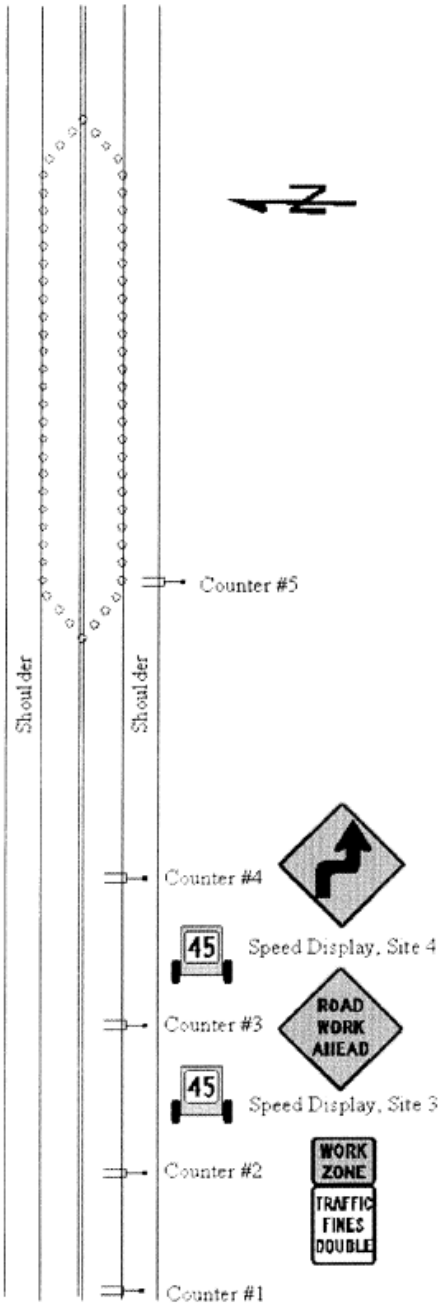
Mean speed dropped significantly for cars at one site, by 9.0 mph, and dropped insignificantly for cars at one site.

For H1, the percent of drivers over the speed limit dropped significantly for both cars and trucks at one site, by 18 and 16% respectively; there were no significant changes at the other site. For H2, the percent of drivers over the speed limit dropped significantly for cars at one site, by 20 percent, but not for trucks. There were no significant changes at the other site.

Statistical Analysis. Authors conducted chi-square testing and identified the significant results (when comparing the DSFS treatment to "Normal Traffic Control"). Details of the statistical testing were not provided.

12.4. Study Schematic

Image courtesy of the author and reproduced with permission of the Transportation Research Board.


Shoulder
Shoulder
Counter #5
Counter #4
45
Speed Display, Site 4
Counter #3
ROAD WORK AHEAD
45
Speed Display, Site 3
Counter #2
WORK ZONE
TRAFFIC FINES DOUBLE
Counter #1

(b)

12.5. DSFS Graphic

Image courtesy of the author and reproduced with permission of the Transportation Research Board.

13. Fontaine, 2008

13.1. Study Characteristics

Item	Response
Authors	Fontaine
Title	Innovative Traffic Control Devices for Improving Safety at Rural Short-Term Maintenance Work Zones
Publication year	2008

13.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Reduction recorded, but no information on statistical significance.
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Reduction recorded, but no information on statistical significance.
H1: Distribution of speed	Nothing reported
H2: Mean speed	Reduction recorded, but no information on statistical significance.
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Reduction recorded, but no information on statistical significance.
H2: Distribution of speed	Nothing reported

Feature	Study Information
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	70 mph
Sensor positions	NS
Number of sensors	0,1,1
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	4
Number of cases	4
Duration of measurements before activation (“before” measurements)	Half day
Time interval between “before” measurements and activation	Immediately before
Duration of activation	Half day
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	NS

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[14]	Half day
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	NA
Best practices information available	No

13.3. Summary of Study

This study evaluated the safety effectiveness of traffic control devices at short-term, rural, highway maintenance work zones in north Texas. The study evaluated speed display trailers, radar drones, and three other strategies. The speed display trailer detected speeds with radar and displayed them to drivers with LED numerals 24 inches high. It also had a strobe light that flashed when vehicles were detected traveling more than 5 mph over the speed limit. All test sites had 70 mph posted regulatory speed limits and level grades. A mix of four-lane and two-lane sites were evaluated, and the length of the activity area at these sites was typically between ¼ and ½ mile. In all cases, the work sites were only in place during the day for a single day. Over the first half of the day data were collected before implementing the speed display trailer. Mid-way through the day researchers activated the speed display trailer and began collecting "during" data. The speed display trailer was evaluated at four sites. Researchers used LIDAR guns to measure vehicle speeds.

In addition to measuring speeds, researchers videotaped the area to examine conflicts between vehicles, such as late merges, sudden braking maneuvers, or other actions that caused surrounding vehicles to brake or perform evasive action. They also interviewed workers at the job site to ask about the usability of the devices for short-term operations. Finally, they interviewed some drivers to determine their opinions on the measures being evaluated.

The measures of effectiveness were mean speed and the percent of vehicles exceeding the speed limit. The hypotheses investigated were H1B and H2B.

Data reported. Mean speeds and percent of vehicles exceeding the speed limit.

Results. In general, the speed trailer was effective in reducing vehicle speeds at all four sites. Mean speeds were reduced by an average of 5.2 mph in the advance warning area for both cars and large trucks. Speed reductions were slightly less in the activity area of the work zone.

[14] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Statistical Analysis. No information on statistical significance or statistical analysis was provided.

13.4. Study Schematic

Not provided.

13.5. DSFS Graphic

Not reproduced here. See article.

14. Gambatese and Zhang, 2014

14.1. Study Characteristics

Item	Response
Authors	Gambatese and Zhang
Title	Safe and Effective Speed Reductions for Freeway Work Zones, Phase 2
Publication year	2014

14.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O-X-O-X-O-X-O-X-O
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	na
Hypothesis 3 (H3) level	na
H1: Mean speed	No change
H1: 85th percentile speed	Reduction recorded for case study 2 (only when DSFS combined with PCMS). Otherwise, No change for DSFS or PCMS alone.
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Significant reduction recorded for case study 2 (only when DSFS combined with PCMS). Otherwise, No change for DSFS or PCMS alone.
H2: Mean speed	NA
H2: 85th percentile speed	NA

Feature	Study Information
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	50 mph
Sensor positions	Upstream (-2 miles, -1 mile); in work zone (every 0.5 miles)
Number of sensors	4,6,0
Sensor types	Multiple (magnetic imaging supplemented with radar and video)
Types of treatments	DSFS + other (portable changeable message sign with no speed feedback)
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation (“before” measurements)	8 hours
Time interval between “before” measurements and activation	1 day
Duration of activation	8 hours
Time of day when speed is measured (a.m./p.m.)	p.m. (night)

Feature	Study Information
Time of day when speed is measured (peak/off peak)	Off peak
Time intervals at which measurements were taken during activation ("during" measurements)[15]	1,2,3,4,5,6,7,8 hours
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	The study noted some methodological problems and unanticipated confounding factors.
Best practices information available	Yes

14.3. Summary of Study

The research study included two case studies on multi-lane freeway paving projects in rural Oregon. For each case study, the researchers implemented combinations of multiple traffic control devices (speed limit signs, PCMS, and DSFS) and evaluated their impacts on vehicle speed. For both case studies, the posted speed limit was 50 mph in the work zone and the paving work and associated experiments took place at night. In both cases, researchers investigated multiple interventions (speed limit sign, portable changeable message sign, and DSFS) and all possible combinations of those three.

Case study 1 was located in Douglas County, Oregon, in a mountainous area with sharp curves and steep grades. Researchers noted in retrospect that on some of the test days, the slow speeds recorded may not be the result of the traffic control treatments employed for the research. The slow speeds may be solely due to the grade, roadway curves, and presence of slow trucks. In total, researchers collected data over seven days, but they could not compare or aggregate data across all seven days because the location of the road segment varied. Instead, they did three separate analyses grouping only the days with the same location. The first grouping (days 1, 2, 3) and third grouping (days 6, 7) are most relevant in that they included DSFS as one of the interventions.

Case study 2 was located on I-5 between Grants Pass and Medford. The roadway in this section of I-5 is predominantly straight and almost flat with no grade or horizontal curve impacts on vehicle speed.

[15] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

The data collection equipment and procedures were similar for both case studies. Measures were taken of the mean speed and 85th percentile speed. The measurement period for each treatment condition was approximately 8 hours, overnight, with one day in between each treatment condition and associated measurement period. Researchers primarily used 10 magnetic imaging sensors at seven locations, but also supplemented this with radar speed guns and video recording. The 10 magnetic imaging sensors were placed on the roadway for each work period (night of paving). The first two analyzers were placed approximately 1 mile upstream of the "Road Work Ahead" sign to capture vehicle speeds before the vehicles became aware of the work zone. Two analyzers were placed near the "Road Work Ahead" sign, which is typically approximately 1 mile upstream of the actual work area. Two analyzers were placed at the beginning of the lane taper at the start of the work zone, and one analyzer was placed at the end of taper. Three analyzers were placed in the traveling lane at different points in the work zone. According to the study, the actual location and spacing of the last three analyzers in the work zone was dependent on the amount and location of work being performed on the given night.

When the PCMS on trailers and DSFS were used, they were typically initially located after the end of the taper and before the start of the paving area. Later in the work shift, as the paving work progressed downstream, these traffic control measures were not as close to the work activity, so the contractors moved the measures downstream in the middle of the night. However, researchers noted that the timing of when these were moved and the new location relative to the paver were not consistent from one day to the next; this inconsistency may have confounded some of the results.

The DSFS displayed the speed, but the study did not specify the method of illumination or the presence/absence of flashing.

Independent variables were as follows: treatment (traffic control devices), vehicle length, time of day, and distance from paving work. Dependent variables were as follows: mean speed, 85th percentile speed. The major hypothesis evaluated was H1B.

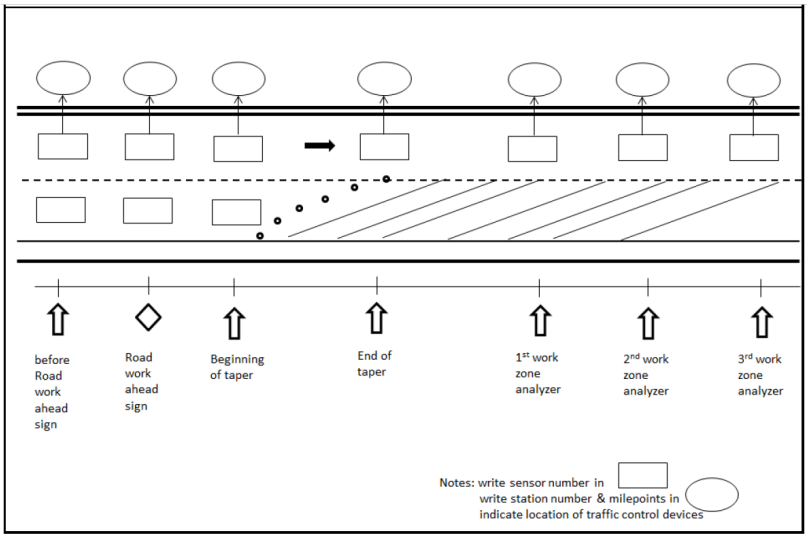
Data Reported. The article reported mean speeds, 85th percentile speeds, sample sizes, standard deviations, and whether or not observed changes in mean speeds and 85th percentile speeds were statistically significant.

Results. The DSFS did not cause a statistically significant reduction in mean speed. In some cases, there was actually an increase in mean speeds, but the researchers surmise that this may have been related to confounding factors that they did not originally anticipate. On Day 3 of case study 1 (the only day with the DSFS), the contractor paved the roadway shoulder and fully closed the slow lane, moving the passing traffic farther away from the actual work taking place. One may expect that the vehicle speeds would be greater in this case than if the work were directly adjacent the travel lane. That is, when a closed, "buffer" lane is provided, vehicle speeds tend to increase. In case study 2, the DSFS similarly did not cause a statistically significant reduction in mean speed. However, the combination of DSFS with PCMS did result in a statistically significant reduction in the 85th percentile speed, as well as a reduction in the standard deviation.

Statistical Analysis. Two sample t-tests were applied to compare speeds.

14.4. Study Schematic

Image courtesy of the authors.



Placement of Traffic Control Analyzers (Sensors)

14.5. DSFS Graphic

Not available

15. Gambatese and Jafarnejad, 2015

15.1. Study Characteristics

Item	Response
Authors	Gambatese and Jafarnejad
Title	Evaluation of Radar Speed Display for Mobile Maintenance Operations
Publication year	2015

15.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	No
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	No
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Multiple
Sidewalks present	No
Posted speed	55 mph
Sensor positions	Upstream (NS); in work zone (varied)
Number of sensors	1,5-6,0
Sensor types	Multiple (magnetic imaging, radar, and video)
Types of treatments	DSFS (intermittent mobile operations with frequent stops) and DSFS (continuous mobile operations)
Number of relevant sites	4
Number of cases	8
Duration of measurements before activation ("before" measurements)	Case 1: 3 hours. Case 2: 35 minutes. Case 3: 48 minutes. Case 4: 1 hour
Time interval between "before" measurements and activation	Case 1: 1 day. Case 2: 20 minutes. Case 3: 1 day. Case 4: 40 minutes
Duration of activation	Case 1: 3 hours. Case 2: 23 minutes. Case 3: 77 minutes. Case 4:1 hour
Time of day when speed is measured (a.m./p.m.)	Multiple (night for case studies 1-3, Day-a.m. for case study 4)
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[16]	Entire duration
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	Yes, but dispersed throughout the report

15.3. Summary of Study

This research study evaluated the impact of truck-mounted DSFS on vehicle speeds in mobile maintenance work zones. In a mobile maintenance work zone, the truck moves with a low speed (usually 5 to 10 mph) behind the maintenance equipment conducting the work to provide warning to approaching vehicles about the work zone and to advise a decrease in speed. Thus, this research was unique from most other papers in that the location of the DSFS in the study areas was not fixed; it moved with the truck throughout the work zone over the course of the observation periods.

The research study includes four case studies on multi-lane freeway maintenance projects in Oregon. The first two case studies were located at the same site. The first three studies were in the Portland metropolitan area (urban) and involved night operations and the fourth was in the Klamath Falls area (rural) and involved daytime operations. In all cases the speed limit was 55 mph. The case studies were as follows.

- Site 1 (I-205):
    - Case Study #1: Relamping, i.e., an intermittent mobile operation involving frequent short stops near each light pole with a complete lane closure
    - Case Study #2: Sweeping, i.e., a continuously moving mobile operation without a complete lane closure
- Site 2 (I-84 Banfield Expressway), Case Study #3: Vactoring, i.e., an intermittent mobile operation involving frequent short stops cleaning the drains along the right shoulder of the roadway, without a complete lane closure
- Site 3 (US-97), Case Study #4: Weed spraying, i.e., a continuously moving mobile operation during the day with no lane closure.

[16] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

For each case study, the researchers conducted two periods of testing – one with the DSFS display turned on and one with the display off, and recorded vehicle speeds. Measures were taken of the mean speed, 85th percentile speed, percentage of vehicles traveling above the speed limit, mean speed difference between adjacent vehicles, and mean distance between adjacent vehicles.

The sites used sensors at one upstream site (unspecified distance but co-located with a "road work ahead" sign) for each study, and 5 or 6 sites in the work zone. At each location, a unique sensor was placed in each lane. The measures were gathered before and during the time that the DSFS was activated. There were no measurements after the DSFS was removed. For studies 1 and 3, 1 day intervened in between the before and during observations. For studies 2 and 4, the "during" observations immediately followed the "before" observations on the same day. All DSFS displayed the speed via LED lights, but did not flash. Independent variables were as follows: treatment, volume and mix of traffic, roadway location and design, and type of work activity. Dependent variables were as follows: mean speed, 85th percentile speed, percentage of the sample exceeding the speed limit, mean distance between adjacent vehicles and mean speed difference between adjacent vehicles. The major hypothesis evaluated was H1B.

Data Reported. The article reported mean speeds, sample sizes, standard deviations, and whether or not observed changes in mean speeds were statistically significant. The article also reported 85th percentile speeds and the percent of drivers exceeding the speed limit, but did indicate whether these changes were significant.

Results. Overall, the DSFS display proved to be effective in reducing vehicle speeds in the work zone compared to when the DSFS was not used. This impact was observed for both continuously mobile operations (e.g., sweeping and spraying) and intermittent operations (e.g., relamping and vactoring[17]). The magnitude of impact varies from one project to another depending on multiple factors such as the volume and mix of traffic, roadway location and design, and type of work activity. The quantitative analyses of the speed data from the four case study projects included in this research study revealed that the DSFS resulted in the following.

- A larger decrease in vehicle speeds from the upstream (at the "Road Work Ahead" signs) to the active work area. For the case study projects evaluated, 85th percentile speeds decreased approximately 2 to 5 mph (4% to 8%) without the RSS turned on and 3 to 13 mph (5% to 23%) with the RSS turned on.
- A lower percentage of vehicles traveling above the speed limit
- Smaller differences in speeds between adjacent vehicles
- Smaller distances between adjacent vehicles

Based on the findings, the researchers recommend use of truck-mounted radar speed signs during mobile maintenance operations on high-speed roadways.

Statistical Analysis. The authors tested for statistical significance and reported whether differences in means speed were statistically significant. They also conducted statistical tests to explore the effect of vehicle type (passenger vehicle or truck) on mean speed with and without

[17] Editor's note: "Vactoring" uses a truck mounted with a mechanical high-suction vacuum, pressure washer, and tanks to hold water and waste water typically used for drainage and sewer cleaning.

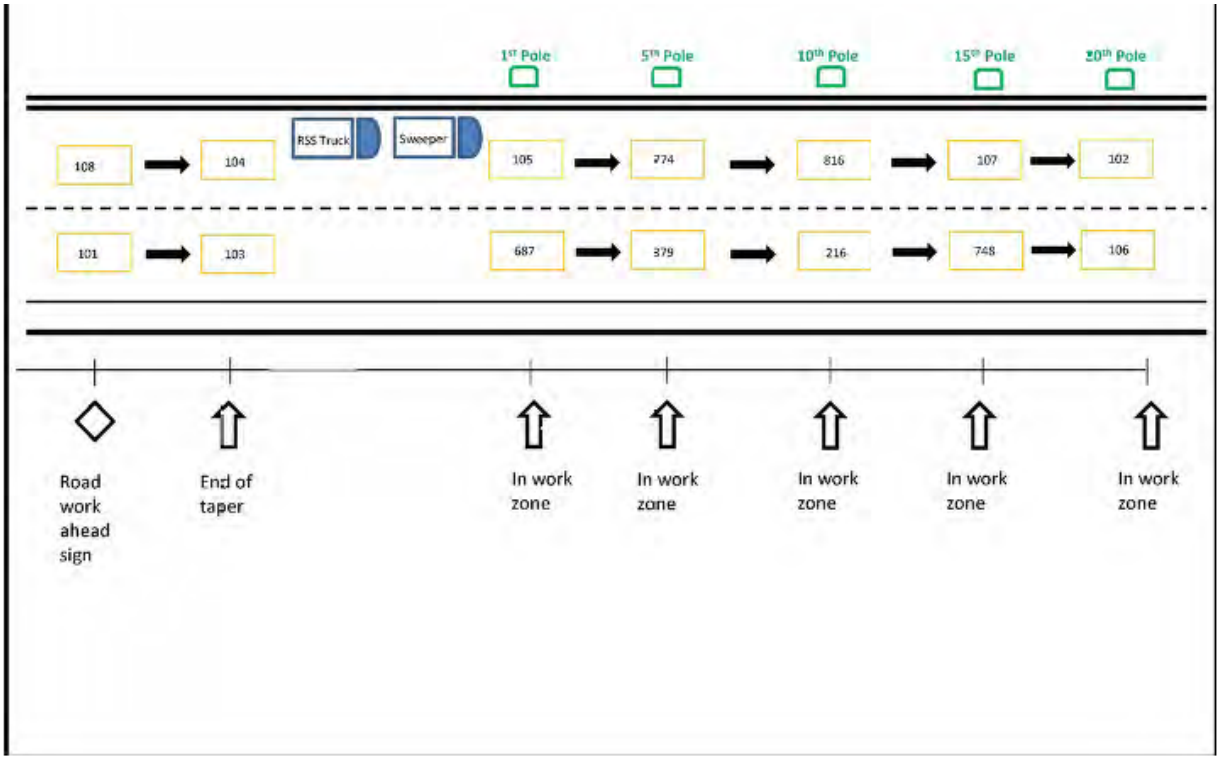
the DSFS display turned on. The results indicated that for site 1 (case studies 1 and 2) trucks had a greater mean speed difference from the "before" to the "during" condition, as compared to passenger vehicles, and this apparent difference by vehicle type was statistically significant. For sites 2 and 3, there was no statistically significant difference between cars and trucks.

15.4. Study Schematic

Case Study #1: See figure 3.11 in article. Not reproduced here.

Case Study #2, 3, and 4: See figure 3.10 in article. Not reproduced here.

Case Study #2 sensor placement (image courtesy of the authors):



Traffic Sensor Layout during Sweeping Operation, SB I-205 (Case Study #2)

15.5. DSFS Graphic

Images courtesy of the authors.

(a) (b)

Advisory Speed Sign during (a) First Night of Testing and (b) Second Night of Testing (Case Study #3)

16. Hajbabai, Medina, Want, Benekohal, and Chitturi, 2011

16.1. Study Characteristics

Item	Response
Authors	Hajbabai, Medina, Want, Benekohal, and Chitturi
Title	Sustained and Halo Effects of Various Speed Reduction Treatments in Highway Work Zones
Publication year	2011

16.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O-X-O
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	B
H1: Mean speed	Significant decrease
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	NS
Sidewalks present	No
Posted speed	55 mph
Sensor positions	Adjacent (200 ft)
Number of sensors	1
Sensor types	Video
Types of treatments	Speed display trailer, police enforcement with speed display trailer, speed photo enforcement
Number of relevant sites	2
Number of cases	6
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Off peak
Time intervals at which measurements were taken during activation ("during" measurements)[18]	NS

[18] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	Less than 1 hour
Duration of "after" measurements	NS
Meta-analysis data available	Yes
Caveats	No
Best practices information available	No

16.3. Summary of Study

The safety focus was a work zone on an interstate highway in Illinois. There were two sites, Site 1 and Site 2. At both sites, the roadway was straight, with two lanes of traffic going in one direction. Only free-flowing traffic was included in analysis, with "free-flow" defined as 4 seconds of headway at 55 mph. Four treatments were evaluted: speed display trailer (SDT), police (lights off), speed display trailer and police (lights off), and automated speed photo-radar enforcement (SPE). Both the SDT and SPE displayed the speed to the drivers as they passed the device. At Site 1, data were gathered during the a.m. off-peak hours (Data Set 1) and p.m. off-peak hours (Data Set 2) at one location before, during and after treatment. At Site 2, data were gathered during the p.m. off-peak hours at one location before, during and after treatment. Four independent variables were considered: treatment (baseline, SFT, police, police+SFT, SPE); vehicle class (trucks, cars); lane (right, left lane); free flow (yes, general). Measures were taken of the mean speed, speed distribution, and percentage of speeding drivers (extreme and moderate). The sensor was a video recorder capturing 30 frames per second, with two markers that allowed speed to be determined precisely from the frames. This allowed the data to be sorted by vehicle type, lane traveled, and level of service. The sensor data covered a trapezoidal area from the DSFS to approximately 700 feet downstream. The measures were gathered before (unspecified), during, and after (less than 1 hour) the treatment. Data was analyzed for each location separately. The major hypotheses were H1B and H3B.

Data Reported. The publication reported mean speeds, but did not report mean speed changes for all conditions in data sets 1 and 2 because the drivers in those data stes were already traveling the posted speed. For Data Set 3, mean speed reductions were reported for all combinations of independent variables. The study also reported 85th percentile speeds, the distribution of speeds, and the percentage of excessive and moderate speeders.

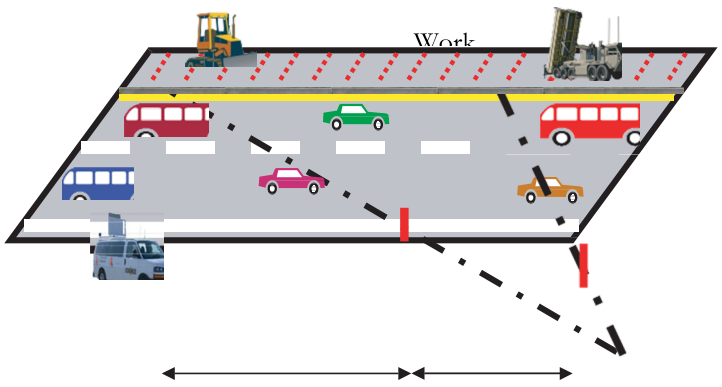
Results. "The results indicated that the SPE system and police–trailer treatments reduced the mean speed of both the general traffic stream and free-flowing vehicles by about 5 to 7 mph. The magnitudes of the speed reductions while the treatments were deployed were sustained over time. Police presence alone also reduced the speed significantly but to a lesser degree, and the effects of the trailer treatment alone were limited."

Statistical Analysis. "The statistical significance of these changes was estimated by the following techniques: (a) t-tests, to evaluate the changes in the mean speeds; (b) least-significant-difference tests, to determine if the speeds changed after the treatments were deployed and

removed; and (c) chi-square and Kolmogorov–Smirnov tests, to determine if the speed distributions for two different treatments were the same. In addition, the effects of the treatments on the mean speeds were determined over time to establish whether the effects decreased immediately after the treatments were removed from the work zone or were stable. To determine the effects, a moving average of the general traffic stream (when the treatment was present) was calculated every 5 min and plotted over time."

16.4. Study Schematic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.



Schematic diagram of data collection setup

16.5. DSFS Graphic

Not provided

17. Hallmark, Peterson, Fitzsimmons, Hawkins, Resler, and Welch, 2007

17.1. Study Characteristics

Item	Response
Authors	Hallmark, Peterson, Fitzsimmons, Hawkins, Resler, and Welch
Title	Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities
Publication year	2007

17.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Upstream (-2,640 ft), adjacent (just downstream), and downstream (NS)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS alone and DSFS with peripheral transverse pavement markings and median widening
Number of relevant sites	0
Number of cases	0
Duration of measurements before activation (“before” measurements)	48 to 72 hours
Time interval between “before” measurements and activation	NS
Duration of activation	3 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[19]	0 and 3 months
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

17.3. Summary of Study

The study evaluated traffic-calming treatments on major roads going through small Iowa communities. Seven different low-cost traffic treatments were implemented and evaluated in five rural Iowa communities. Union and Slater were the two communities that included DSFS as one of the evaluated treatments. In Slater, the DSFS was evaluated as a single measure in a single location, whereas, in Union, the DSFS was evaluated in three separate locations as part of an overall "gateway" treatment that also included (1) peripheral transverse pavement markings, and (2) median widening. Each site had an existing speeding problem, as documented by the researchers through preliminary speed testing.

Researchers used pneumatic tubes to collect speed and volume data for each site before the implementation of measures and during implementation at 1, 6, 9, and 12 months. At each instance, data were collected for either a 48- or 72-hour period. However, in Union, the DSFS were not installed until just before the 9-month data collection. In Slater, the DSFS was not installed until just before the 3-month data collection, and data were only collected for one "during" period.

In Union, data were collected 0.5 miles upstream, immediately downstream of the devices, and at one other location some additional unspecified distance downstream. In Slater, data were only collected immediately downstream of the device.

In Union, the DSFS would not activate unless the approaching vehicle speed were to exceed 25 mph. It would then begin displaying speeds, with flashing above 45 mph. The DSFS was programmed to not display the speed above a certain threshold (50 mph in one instance and 55 mph in another). In Slater, the DSFS would not activate unless the approaching vehicle speed were to exceed 25 mph. It would then begin displaying speeds up to 40 mph. At speeds above 40

[19] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

mph it flashed “Slow Down 25), and then stopped displaying anything for vehicles traveling over 75 mph.

The measures of effectiveness were mean speed; standard deviation; 85th percentile speed; minimum speed; maximum speed; and percent of vehicles traveling at or above 5, 10, 15, 20, and 25 mph over the posted speed limit. The study evaluated hypotheses H1B and H2B.

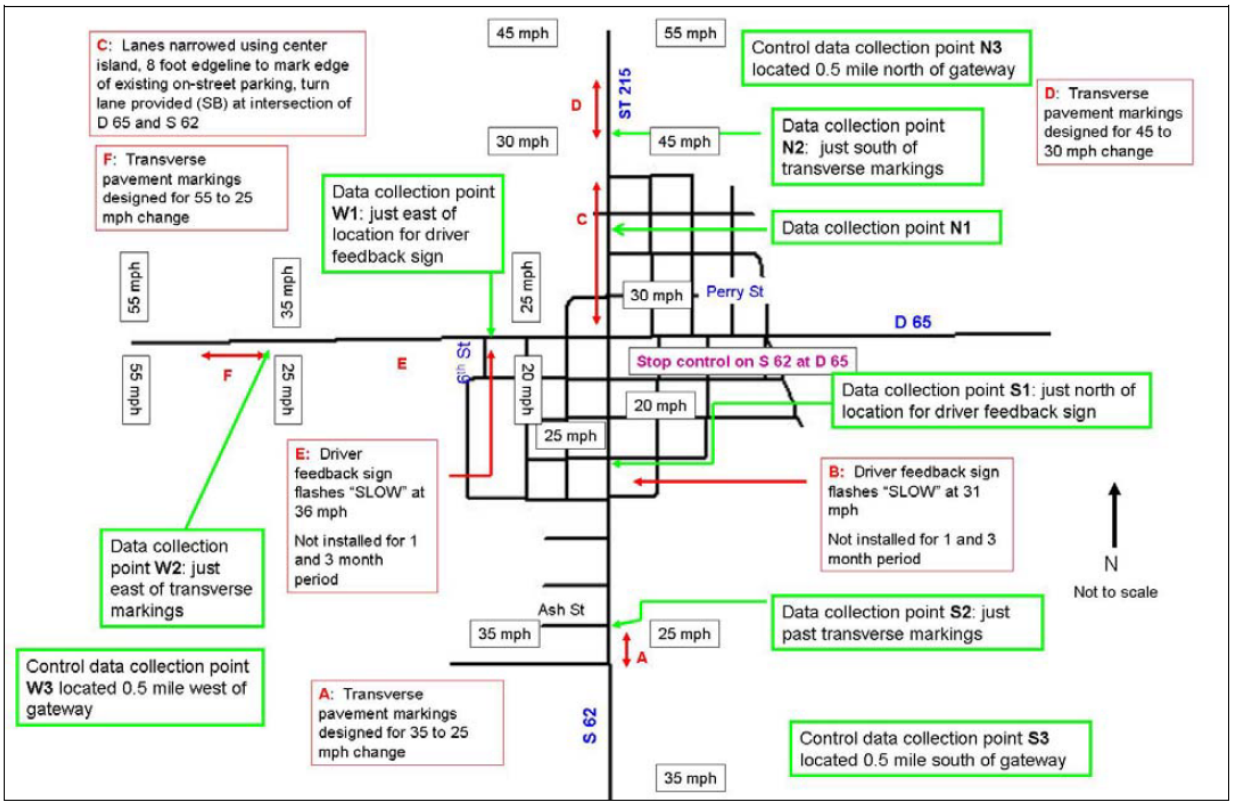
Data reported. Mean speed; standard deviation; 85th percentile speed; minimum speed; maximum speed; and percent of vehicles traveling at or above 5, 10, 15, 20, and 25 mph over the posted speed limit.

Results. In Union, the other two speed calming measures showed only slight effectiveness. Once the DSFS were installed significant speed reductions were recorded. Speed data for Union were also evaluated by time of day (a.m. vs. p.m., peak versus off-peak), but no distinguishing pattern emerged. In Slater there was a statistically significant decrease in mean speed during DSFS activation.

Statistical Analysis. “Mean speeds were compared at either the 90 or 95% confidence level using a t-test (assuming unequal variances). All datasets were evaluated to ensure that they were normally distributed before the t-test was applied. The percentage of vehicles traveling at 5, 10, 15, 20, and 25 mph above the posted speed limit were compared from the before to after periods at the 90 or 95% confidence level using a statistical test to infer differences between two population proportions (Ott & Longnecker, 2001).”

17.4. Study Schematic

Image courtesy of the authors.



Data collection locations for Union

17.5. DSFS Graphic

Image courtesy of the authors.

18. Hallmark, Hawkins, and Knickerbocker, 2015

18.1. Study Characteristics

Item	Response
Authors	Hallmark
Title	Use of DSFS as a Speed Transition Zone Countermeasure in Small, Rural Communities
Publication year	2015

18.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Multiple
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Multiple
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Adjacent (NS)
Number of sensors	0,1,0
Sensor types	Pneumatic
Types of treatments	DSFS (3 types)
Number of relevant sites	6
Number of cases	6
Duration of measurements before activation ("before" measurements)	24-48 hours
Time interval between "before" measurements and activation	NS
Duration of activation	12 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[20]	1 month, 12 months

[20] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

18.3. Summary of Study

DSFSs were installed at six sites in Iowa. The context was rural, specifically highways with speed limits of at least 50 mph entering rural communities with speed limits less than 40 mph. The roadways were paved highways with "no unusual geometry." The posted speeds were as follows: 25 mph at 5 sites, 30 mph at one site. Measures were taken of the mean speed, 85th percentile speed, and fraction of drivers exceeding the speed limit by 5, 10, and 15 mph at six sites. Sensors were placed at or slightly downstream of the DSFS; exact locations were not specified. The measures were gathered before and during (1 month, 12 months) the time that the DSFS was activated. There were no measurements after the DSFS was removed. Each set of measurements was taken over one 24 or 48 hour period, on a non-holiday weekday. Data was analyzed for each location. Three different styles of DSFS were applied, but all involved a dynamic visible response to speeding. Independent variables were as follows: treatment and duration of treatment. Dependent variables were as follows: mean speeds, 85th percentile speeds, and percentage of the sample exceeding the speed limit. The major hypothesis evaluated was H1B. The measures of effectiveness were mean speed, 85th percentile speed, and fraction of vehicles exceeding the speed limit (grouped by severity of speeding).

Data Reported. The article reported mean speeds, 85th percentile speeds, sample sizes, and fraction of drivers exceeding the speed limit by 5+, 10+, and 15+ mph. It did not provide variance, standard deviation, or significance data.

Results. For H1B, mean speed dropped at all sites. It is not clear whether the changes were statistically significant. At 5 of the 6 sites, mean speed decreased between 4.6 and 7.9 mph; at one site the mean speed dropped by 0.4 mph. When comparing the data from a 1 month installation with a 12 month installation, mean speed increased by 1.7 mph and by 0.5 mph at two sites and decreased by 0.2 mph at the third site. Malfunctions or other factors prevented 12 month measurements at the other sites. Again, it is not clear whether these changes are statistically significant. All sites showed a decrease in the percent of vehicles traveling 5+ and 10+ mph over the posted limit; 5 of the 6 sites showed a decrease in the percent of vehicles traveling 15+ mph over the posted limit, while one site showed an increase in this number. It is noted that the increase, from 4 percent to 5 percent, is not statistically significant at the 95 percent level. The changes in the percentage of vehicles driving at least 10 mph over the speed limit are as follows at the six sites: from 64 percent to 17 percent; from 19 percent to 5 percent;

from 86 percent to 65 percent; from 29 percent to 3 percent; from 18 percent to 16 percent; from 67 percent to 40 percent.

Statistical Analysis. The details of the statistical analysis conducted are not specified, but some results are called out as *not* significant at the 95% confidence level; we therefore assume that other described results are significant.

18.4. Study Schematic

Not provided.

18.5. DSFS Graphic

Images courtesy of the authors.

Sign showing driver speed at rural community entrance

LED Lights with speed limit sign

19. Hallmark, Hawkins, and Smadi, 2015

19.1. Study Characteristics

Item	Response
Authors	Hallmark, Hawkins, and Smadi
Title	Evaluation of Dynamic Speed Feedback Signs on Curves: A National Demonstration Project
Publication year	2015

19.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	A,B
Hypothesis 2 (H2) level	A,B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant decrease
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant decrease
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Multiple
DSFS speed lighting	Yes
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Multiple
Area type (location)	Rural
Sidewalks present	No
Posted speed	At least 50 mph in preceding tangent section
Sensor positions	Upstream (-2,640 ft), adjacent (point of curvature), and downstream (distance varied;at center of curve)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS speed display and DSFS curve warning
Number of relevant sites	22
Number of cases	22
Duration of measurements before activation ("before" measurements)	2 days
Time interval between "before" measurements and activation	NS
Duration of activation	24 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[21]	1 month, 12 months, 24 months

[21] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

19.3. Summary of Study

This national demonstration project evaluated the effectiveness of two different DSFS types in reducing speed and crashes on curves at 22 sites on rural two-lane roadways in seven States: Arizona, Florida, Iowa, Ohio, Oregon, Texas, and Washington.

Each site had to meet the following criteria:

- High historical crash totals;
- Existing speeding problem;
- No rehabilitation or reconstruction activities that change the geometry of the roadway scheduled during the 2-year project;
- No geometric or cross-section changes made for 3 years prior to the study;
- Posted speed limit on preceding tangent section 50 mph or greater; and
- Far from any major development, railroad, or major access points, including intersections other than low-volume intersections.

Out of 51 identified viable sites across the States, the researchers randomly selected 22 treatment sites, and the remaining 29 sites served as control sites for the crash analysis. Speed data were only collected at the treatment sites and comparisons were made of speed at the treatment sites before and after installation of the DSFS. Table 24 in the publication shows the final list of selected sites and their characteristics.

The two different DSFS types evaluated were as follows.

- **Speed display.** Displays the vehicle's actual speed, up to a certain threshold, and then the speed indication is replaced by the actual posted speed limit.
- **Curve warning.** Displays a warning to slow down due to the curve ahead.

Regardless of the type, they both activated when drivers exceeded the 50th percentile speed.

In most cases, researchers collected 48 consecutive hours of data for each instance. Data were collected before (exact timing unspecified) and at 1, 12, and 24 months during implementation of the DSFS. Data were collected at three locations for each site: 0.5 miles upstream from the curve, at the point of curvature (PC) where the sign was installed, and at the center of curve (CC). Speed and volume data were collected using pneumatic road tubes and counters. The study evaluated hypotheses H1A, H1B, H2A, and H2B.

Data reported. Average daily traffic, sample size, mean speed, standard deviation, 85th percentile speed, and percent of vehicles exceeding the advisory speed limit by 5, 10, 15, and 20 mph (if no advisory speed limit, this was calculated for the regulatory speed limit).

Results. Across all treatment sites, speeds decreased on average by 1.8 mph at 1 month, 2.6 mph at 12 months, and 2.0 mph at 24 months. The 85th percentile speed decreased by 2.2 mph at 1 month, 2.9 at 12 months, and 2.2 mph at 24 months. The fraction of vehicles traveling 10 mph or more over the posted or advisory speed decreased by an average of 30 percent at 1-month, 34 percent at 12 months, and 30 percent at 24 months. Larger decreases were noted for the speed signs than for the curve signs, although differences were not statistically significant. Speed reductions were generally larger at the center of the curve than at the point of curvature. In addition, nighttime versus daytime speeds were compared for several sites, and passenger vehicle versus heavy truck speeds were compared for several sites. No major differences in speed reductions were noted for either of these comparisons. Crashes in both directions decreased by 0.08 crashes per quarter for the control sites, while crashes per quarter at the treatment sites decreased by 0.22 (a 17% versus 40% reduction).

Statistical Analysis. "The changes in mean speeds from the before to the after periods were evaluated using a t-test, and the changes in the fraction of vehicles traveling over the posted or advisory speed by a certain threshold were compared using a test of proportions. Unless indicated otherwise, differences in means and percent over the posted or advisory speeds were statistically significant at the 95-% level of significance… A simple descriptive statistical analysis compared reductions in crashes from the before to after period for treatment versus control sites… A before-and-after analysis was also conducted using a Full Bayes Model to develop crash modification factors (CMF)."

19.4. Study Schematic

See Figure 44 in article.

19.5. DSFS Graphic

See Figure 1 and Figure 2 in article.

20. Hallmark, Knickerbocker, and Hawkins, 2013

20.1. Study Characteristics

Item	Response
Authors	Hallmark, Knickerbocker, and Hawkins
Title	Evaluation of Low Cost Traffic Calming for Rural Communities – Phase II
Publication year	2013

20.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Multiple
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Multiple
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Upstream (NS) and adjacent
Number of sensors	1,1,0
Sensor types	Pneumatic
Types of treatments	DSFS, radar-activated speed limit sign ringed with LEDs
Number of relevant sites	3
Number of cases	3
Duration of measurements before activation ("before" measurements)	48 hours
Time interval between "before" measurements and activation	NS
Duration of activation	12 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[22]	1 month, 12 months

[22] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

20.3. Summary of Study

This study evaluated various countermeasures that agencies can use to reduce speeds in transition zones as drivers enter rural communities located on high-speed roadways. Tests were conducted at multiple sites, but only two of the sites had treatments that were relevant:

- St. Charles, Iowa: A radar-activated LED-fringed speed limit sign was placed at the east entrance to the town, where the speed limit was 25 mph. The sign did not display motorist speed, but speeds above a certain threshold did cause the LED lights to turn on.
- Rowley, Iowa: A DSFS that showed the speed of approaching vehicles was installed at the east entrance to the town, where the speed limit changed from 55 mph to 25 mph. A radar-activated LED-fringed speed limit sign was installed at the west entrance to Rowley, also at a speed limit transition from 55 to 25 mph.

Pneumatic road tubes were used to collect speed and volume data before and during implementation (at 1 month and 12 months), typically adjacent to or just downstream of the treatment. Data were also collected at an upstream location, at an unspecified distance, where drivers were not yet influenced by the treatment. Data were typically collected for 48 hours on a Monday through Friday under mostly dry weather conditions. In a few cases, due to issues with the traffic counters, data were available for only a 24-hour period. The measures of effectiveness were mean speed, 85th percentile speed, standard deviation, and percentage of drivers exceeding the speed limit. The hypothesis investigated was H1B.

Data reported. Sample size, mean speed, 85th percentile speed, standard deviation, and percentage of drivers exceeding the speed limit by 5, 10, and 15 mph were reported. The study also reported upstream mean speeds.

Results. The radar-activated LED-fringed speed limit sign resulted in minor changes 1 month after installation of the sign, with minor reductions in mean speed and with the fraction of vehicles traveling 5 or 10 mph over the speed limit. The fraction of vehicles traveling 15 or more mph over the limit increased from 4 to 5 percent (a 25 % increase). No changes were noted in the upstream comparison site. Results for the 12 month after period were similar to the 1 month after period, except that the fraction of vehicles traveling 10 or more mph over the limit decreased 22 percent and those traveling 15 or more mph over the limit decreased 25 percent.

Results for the DSFS at the east entrance to Rowley showed mean speed decreased by almost 8 mph 1 month after installation of the DSFS and the 85th percentile speed decreased by 9 mph. There was also a large decrease in the fraction of vehicles traveling over the posted speed limit. The 12-month results were similar but slightly less pronounced.

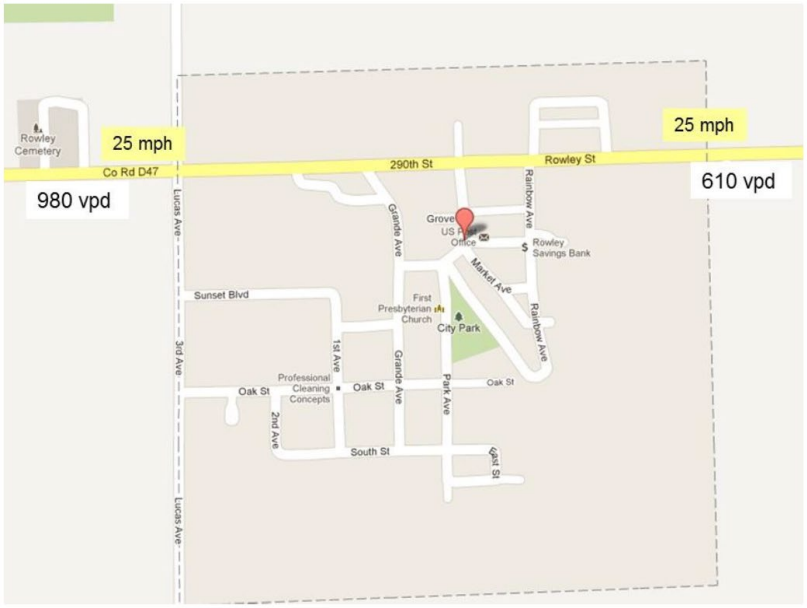
Results for the radar-activated LED-fringed speed limit sign at the west entrance to Rowley showed a decrease of almost 6 mph in mean speed and 7 mph in 85th percentile speed occurred 1 month after installation of the sign. The percent of vehicle exceeding the speed limit also decreased significantly. The 12-month results were similar to the 1-month results.

Statistical Analysis. "Change in average speed between analysis periods were compared at the 95% confidence level using a t-test (assuming unequal variances). Eighty-fifth percentile speeds were also compared, although there is no simple statistical test to compare whether the differences are statistically significant. For the percent of drivers exceed the speed limit, a z-test was used to detect differences between two population proportions at the 95% confidence level. Unless indicated otherwise, differences reported in the publication were statistically significant at the 95% level of significance."

20.4. Study Schematic

Images courtesy of the Institute for Transportation.

Location of treatments for St. Charles, Iowa (Google map)



Map of Rowley, Iowa (Google map)

20.5. DSFS Graphic

Image courtesy of the Institute for Transportation.

21. Jeihani, Ardeshiri, and Naeeni, 2012

21.1. Study Characteristics

Item	Response
Authors	Jeihani, Ardeshiri, and Naeeni
Title	Evaluating the Effectiveness of Dynamic Speed Display Signs
Publication year	2012

21.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Multiple
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	C
Hypothesis 2 (H2) level	C
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Nothing reported
H2: Mean speed	No change
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	NS
Roadway type	Multiple
Area type (location)	Urban
Sidewalks present	NS
Posted speed	Multiple
Sensor positions	Upstream (-200 ft); adjacent (10 ft); downstream (900, 1,130, 2,390, and 4,060 ft)
Number of sensors	0,1,4
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	3
Number of cases	3
Duration of measurements before activation ("before" measurements)	1 week
Time interval between "before" measurements and activation	3-4 weeks
Duration of activation	Site 1: 3 months Site 2: 1 week Site 3: 1 week
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[23]	Site 1: 2 weeks and 3 months Site 2: 1 week Site 3: 1 week
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	None
Best practices information available	No

21.3. Summary of Study

DSFSs were installed at three urban sites in Maryland. Site 1 included the northbound three lanes of a six-lane parkway, with a 45 mph speed limit (initially unposted). It was a 1.4-mile stretch without any entrances or exits. Site 2 was a one-lane road in a 25 mph school zone (speed limit initially unposted). Site 3 was a three-lane road, with one lane used for parking after the morning peak period (speed limit 35 mph). Speed limits were as follows: Site 1, 45 mph; Site 2, 25 mph; Site 3: 35 mph. Measures were taken of mean speed and 85th percentile speed. The categorical regression and Bayesian Network analyses also took measures of speed limit compliance. At site 1, these measures were taken upstream, and at five locations downstream. At sites 2 and 3, these measures were taken upstream, at the DSFS, and downstream. The measures were gathered before installing speed limit signs, while signs were installed but before installing DSFS, and during DSFS activation. At Site 1, measures were also gathered again for another "during" measurement once the DSFS had been operating continuously for 3 months. Data were not averaged across the sites. The conventional statistical analysis considered treatment and duration as independent variables and mean speed and 85th percentile speed as dependent variables. In contrast, the categorical regression (CATREG) and Bayesian network (BN) analyses considered day of the week, time of day, speed limit, school zone, lane number, DSFS size, DSFS effective distance, and DSFS effective time as independent variables and considered mean speed and speed compliance as dependent variables. The major hypothesis was H1C. The measures of effectiveness used were mean speed, 85th percentile speed and speed compliance. The article reported mean speeds, 85th percentile speeds, and sample sizes. It also reported variances and F-test results associated with the tests of the hypotheses. The article also reported the results of the CATREG analysis, showing the coefficients for various independent variables and the R-squared value for each regression. Finally, it reported the results of a BN analysis.

[23] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

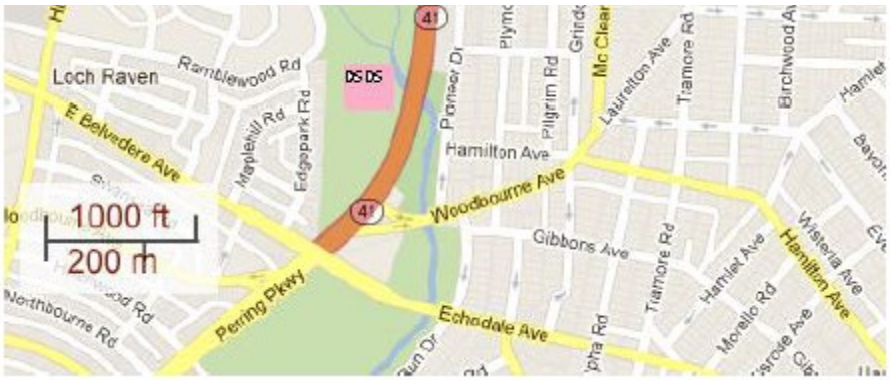
Results. Site 1: The mean speed adjacent to the DSFS was significantly less than the mean speed upstream for a short-term period. However, the average speed was higher at downstream sensor 2, which was 900 feet from the DSFS. The authors concluded that the DSFS affects speed reduction only for a very short distance. Also, the mean speed adjacent to the DSFS was not less than the mean speed upstream for a long-term period. The authors concluded that the DSFS is not an effective long-term tool. The mean speed upstream of the DSFS after three months of operation was more than the mean speed immediately after installation. The mean speed adjacent to the DSFS after three months was not less than the mean speed immediately after the DSFS installation. The mean speed adjacent to the DSFS a short term after installation was less than the mean speed pre-DSFS installation. The mean speed downstream of the DSFS was not less than the mean speed upstream of the DSFS. Site 2: The mean speed adjacent to the DSFS was significantly less than the mean speed upstream for a short-term period. Site 3: The mean speed adjacent to the DSFS was significantly less than the mean speed upstream for a short-term period.

Analysis. The research team performed a conventional statistical analysis of the collected data. Mean speed and variance were calculated for each of the three sites' peak and off-peak periods. The research team also used categorical regression (CATREG), and Bayesian network to assess a DSFS's effectiveness with reducing speed. The conventional statistical analysis was a complete aggregate analysis, which analyzed the average speeds as a single value. The latter methods used a hybrid analysis to aggregate the data (aggregation based on an equal number of vehicles (n) passing a section in an appropriate time interval. Different time periods were used in order to have the same number of vehicles.)

21.4. Study Schematic

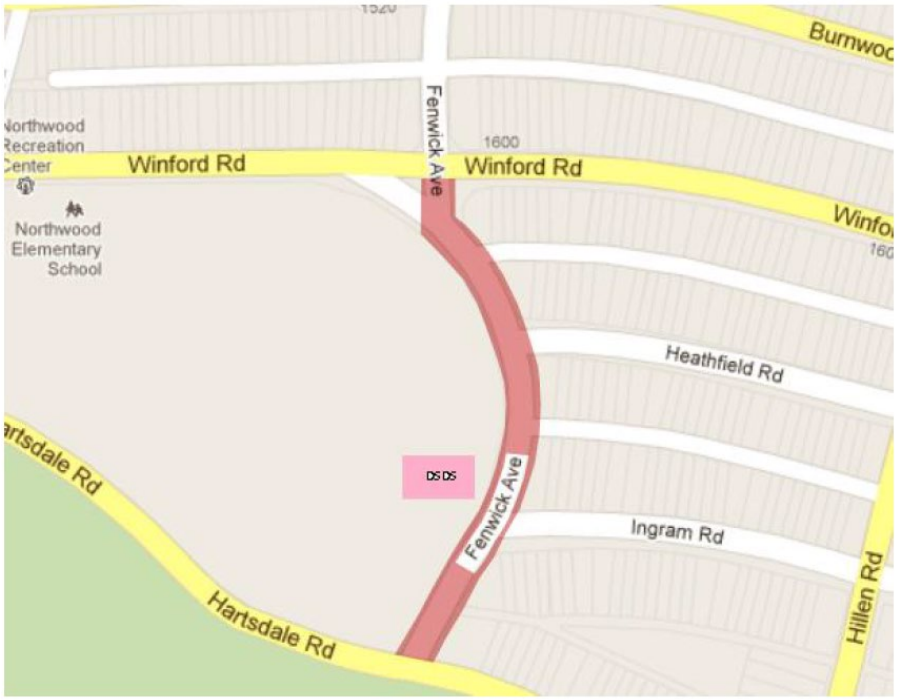
Images courtesy of the authors.

Site 1:



Perring Parkway Study Area

Site 2:



Fenwick Avenue Study Area

Site 3:

Hillen Road Study Area

21.5. DSFS Graphic

Image courtesy of the authors.

22. Kamyab, Andrle, and Kroeger, 2002

22.1. Study Characteristics

Item	Response
Authors	Kamyab, Andrle, and Kroeger
Title	Methods to Reduce Traffic Speeds at High Pedestrian Areas
Publication year	2002

22.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	No change
H2: 85th percentile speed	No change
H2: Percentage of drivers over speed limit	No change for trucks. Decrease for passenger cars, but only for short-term.
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	No
DSFS speed lighting	Yes
DSFS flashes (speed or other)	No
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	No
Posted speed	35 mph
Sensor positions	Downstream (NS)
Number of sensors	0,0,1
Sensor types	Video
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	2 days
Time interval between "before" measurements and activation	1 year
Duration of activation	2 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[24]	2.5 weeks and 9.5 weeks

[24] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	Yes

22.3. Summary of Study

This study evaluated the effectiveness of various speed reduction treatments in rural transition zones where high-speed traffic enters communities with pedestrian traffic. Four sites were evaluated, but only one site, Lake Bemidji, evaluated the effectiveness of a DSFS. The DSFS displayed the word "SLOW" to motorists traveling over the speed limit. "Before" data were collected July 13-14, 2000. The sign was installed the week of June 10, 2001, and then "during" data were collected June 28-30, 2001, and then again August 16-18, 2001. Data were collected at an unspecified distance downstream of the DSFS. Data were collected using two traffic data collection trailers, which had poles with video cameras on top. Videos were later reduced into traffic flow performance data through the use of image processing technology. The study only included data from free-flowing vehicles, defined as those with headways greater than or equal to five seconds. The speed limit was 35 mph. The measures of effectiveness were mean speed; standard deviation; 85th percentile speed; 10 mph pace speed; percent of vehicles in pace speed; mean of the highest 15 percent of vehicles; and percent of vehicles over the posted speed limit. The hypothesis investigated was H2B. Researchers thought that the location of the sign may have been responsible for its limited effectiveness. It was located just after a horizontal curve, such that drivers could not see it until right before they came upon it. They also hypothesized that the single-word message "SLOW" by itself was not informative enough to adequately encourage drivers to slow down.

Data reported. Mean speed; standard deviation; 85th percentile speed; 10 mph pace speed; percent of vehicles in pace speed; mean of the highest 15 percent of vehicles; and percent of vehicles over the posted speed limit were reported.

Results. The DSFS appeared to increase the speed compliance of passenger cars by about 10 percent in short term. Its impact in improving the speed compliance, however, faded after six weeks into the sign operation. It also did not show any statistically significant impact on the speeding percentage of non-passenger cars. Other measures of effectiveness did not show any significant change from the "before" to the short-term "during" condition: mean speed, 85th percentile and pace interval speeds. For the long-term "during" condition, there were significant increases in mean speeds for "passenger cars" and "all vehicles," but a significant decrease in mean speed for "non-passenger cars."

Statistical Analysis. "Statistical comparisons were carried out to ascertain whether the differences of mean speeds and speed compliance rates, obtained in the "before" and "after"

conditions, are statistically significant. Tukey's t-test was used to determine significance of differences in the mean speeds at the 95% confidence level. As for speed compliance rates, the normal approximation to the binomial distribution was used to determine whether the changes in the rates were statistically significant"

22.4. Study Schematic

See Figure 4.7 in article.

22.5. DSFS Graphic

See Figure 5.4 in article.

23. Knapp and Robinson, 2012

23.1. Study Characteristics

Item	Response
Authors	Knapp and Robinson
Title	The Vehicle Speed Impacts of a Dynamic Horizontal Curve Warning Sign on Low-Volume Local Roadways
Publication year	2012

23.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O-X-O-X-O-X-O-X-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	A,B
Hypothesis 2 (H2) level	A,B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	No
DSFS speed lighting	LED
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	No
Posted speed	55 mph regulatory, 35-40 advisory
Sensor positions	Upstream (-0.5 to -0.25 miles); adjacent (NS); downstream (275 to 500 ft)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	3
Number of cases	3
Duration of measurements before activation ("before" measurements)	2-5 days
Time interval between "before" measurements and activation	1 month
Duration of activation	18 months
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[25]	1, 6, 12, and 18 months

[25] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	Yes

23.3. Summary of Study

This research project evaluated the vehicle speed impacts of a DSFS used as a dynamic curve warning sign at three study sites on low-volume, two-lane, rural highways. Two to five days of vehicle speed data were collected 1 month before and 1 month, 6 months, 1 year, and 18 months after the installation of a DSFS at the visually identified point of curvature (PC). Data were collected at three locations in each study site: upstream (typically ¼ to ½ mile from the visually identified initial PC, at the DSFS (at the PC), and downstream (within the curve). Bidirectional vehicle speed data were collected using a pneumatic tube automatic traffic recorder. Measures were taken of the mean speed, 85th percentile speed, minimum speed, maximum speed, sample size, standard deviation of the speed, and percent of vehicles exceeding the speed limit.

The study sites selected were on CSAH 25 and CSAH 3 in Meeker County and CSAH 7 in McLeod County. In each case the DSFS were installed as supplements to existing traditional (i.e. static) curve warning signs. The regulatory speed limit at all sites was 55 mph. In addition, some of the sites had advisory speed limits.

- CSAH 3, advisory speed limit of 40 mph
- CSAH 25, no advisory speed limit
- CSAH 7, advisory speed limit of 35 mph

Independent variables were as follows: treatment and location. Dependent variables were as follows: mean speed, 85th percentile speed, minimum speed, maximum speed, sample size, standard deviation of the speed, and percent of vehicles exceeding the speed limit.

The major hypotheses evaluated were H1A, H1B, H2A, and H2B. However, as it pertains to H1A and H2A, the study only collected data for one "control" location. For one direction of travel, this "control" location was upstream of the DSFS and curve; for the other direction of travel, this "control" site was actually downstream of the DSFS and curve. In this sense, the use of H1A and H2A was slightly different than the standard description enumerated in other reviews.

Data Reported. The article reported mean speeds, 85th percentile speeds, minimum speed, maximum speed, sample sizes, and standard deviations, for both directions of travel at each data collection location.

Results. The overall average of the "before and during" differences (H1B) in mean vehicle speed (for all the data collection time periods) at the visually identified PC location of the CSAH 25 study site was -1.9 mph. This same measure was -7.0 mph at the CSAH 3 study site and -3.0 mph at the CSAH 7 study site. If these overall averages are adjusted for the shifts in upstream speeds, however, (as per hypothesis H1A), they change to -2.5 mph at CSAH 25, -5.2 mph at CSAH 3, and -2.6 mph at CSAH 7. The authors note that the vehicle speed impacts of the DSFS were greatest at the study site with the lowest posted advisory speed limit. The percentage of vehicles traveling at least 5, 10, 15, and 20 mph faster than the posted or advisory speed limit at each study site was also analyzed for each before and during time period comparison. The results showed a reduction in the percentages of vehicles exceeding the speed limit and also suggested that the impact of the DSFS is larger on vehicles traveling at higher speeds.

The authors noted one caveat about the results. When reviewing the data it is also important to take into account an unexpected event at the CSAH 25 study site. After about 9 months of operation the DCWS at the CSAH 25 study site fell during a severe winter event (e.g., high winds and heavy snow) and was not reinstalled for another 3 months. Therefore, the 12-month vehicle speeds collected at CSAH 25, while presented in the report, should not be considered representative of those that might be expected at one year of continuous DSFS operation. The drivers approaching this location likely adjusted their driving to account for the 3-month absence of the DCWS, and then had to readjust to its reintroduction. The same caveat may apply to the 18-month data from this site to the extent that this interruption may have had a lingering effect.

Statistical Analysis. A simple t-test (assuming a normal distribution of data and unequal variances) was applied to determine whether observed differences were statistically significant (with a 95% level of confidence).

23.4. Study Schematic

Not provided.

23.5. DSFS Graphic

Images courtesy of the authors.

Sign Display #1 - Blank

Measured vehicle speed is less than set speed threshold or no vehicle is present.

Sign Display #2 – Activated with "SLOW DOWN" and Top/Bottom Alternating Lights

Measured vehicle speed is equal to or greater than set speed threshold

Dynamic Curve Warning Sign Selected

24. Lee, Lee, Choi, and Oh, 2006

24.1. Study Characteristics

Item	Response
Authors	Lee, Lee, Choi, and Oh
Title	Effectiveness of Speed-Monitoring Displays in Speed Reduction in School Zones
Publication year	2006

24.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	School zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Urban
Sidewalks present	NS
Posted speed	18.6 mph
Sensor positions	Upstream (-545 ft, -381 ft, -190 ft, -131 ft, -66 ft); downstream (66 ft)
Number of sensors	5,0,1
Sensor types	Magnetic
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	24 hours
Time interval between "before" measurements and activation	NS
Duration of activation	12 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[26]	12 months

[26] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	International, thus not included
Best practices information available	No

24.3. Summary of Study

DSFSs were installed at one site in South Korea. The site was urban, and a school zone. The site was a straight section of road following a curved expressway offramp. The roadway was 441m and the study covered approximately the first 186 m. The posted speed was 30 km/h (18.6 mph) throughout, beginning at the first measurement point. Measures were taken of the mean speed, 85th percentile speed, and the distribution of speed data at seven positions: 166m upstream of the DSFS, 116m upstream, 58m upstream, 40m upstream, 20m upstream, at the DSFS, and 20m downstream of the DSFS. The measures were gathered before and during (2 weeks, 12 months) the time that the DSFS was activated. There were no measurements after the DSFS was removed. Each set of measurements was taken over one 24 hour period, on the same day of the week. There was only one site, so the data were not averaged over multiple locations. The major hypotheses were H1B and H2B. To evaluate hypothesis 1, the investigators performed a large sample Z-test on the 2 week data, and similarly on the 12 month data, for each measurement point individually.

Results. The null hypotheses, that there was no difference in the average speed before and during DSFS operation, was rejected for sites 3 to 7 for both the long and short term studies ($p < .0001$). There were statistically significant decreases in mean speed at all locations where the DSFS was noticeable by drivers. When comparing the 2 week and 12 month results, the "level of attention of the drivers to the existence of the [DSFS] was slightly reduced." Drivers began slowing farther downstream than in the 2 week study, and average speed dropped by 3.6 mph at 12 weeks compared to 5.1 mph at 2 weeks. Additionally, the researchers analyzed the distribution of speed data at the DSFS (reference point 6) using the Kolmogorov-Smirnov two-sample test. The analysis of speed distribution showed a significant change in the distribution of speed data at the DSFS site. The percentage of vehicles driving > 31mph dropped from 26.5 percent to 9.9 percent (2 weeks) and 5.4 percent (12 months).

Statistical Analysis. The researchers conducted a large-sample Z-test and reported p-values for their results; most results were significant with $p < .0001$.

24.4. Study Schematic

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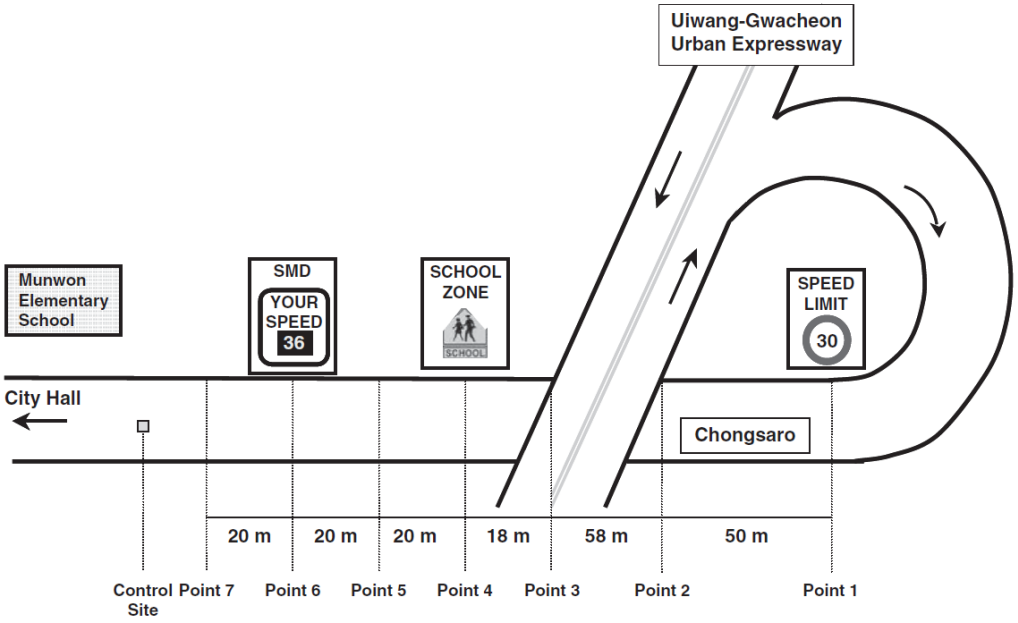

Layout of study school zone (not to scale)

24.5. DSFS Graphic

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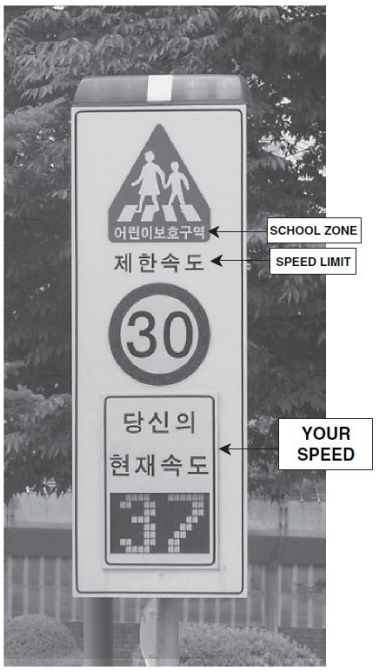

Configuration of SMD in school zone

25. Mattox, Sarasua, Ogle, Eckenrode, and Dunning, 2007

25.1. Study Characteristics

Item	Response
Authors	Mattox, Sarasua, Ogle, Eckenrode, and Dunning
Title	Development and Evaluation of a Speed Activated Sign to Reduce Speeds in Work Zones
Publication year	2007

25.2. Study Features

Feature	Study Information
Experimental design	O-X
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	No
DSFS speed lighting	No
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Multiple
Area type (location)	Rural
Sidewalks present	No
Posted speed	45 mph
Sensor positions	Upstream (-500 ft); adjacent (0 ft); downstream (200 ft and 800 ft)
Number of sensors	1,1,2
Sensor types	Multiple
Types of treatments	DSFS
Number of relevant sites	5
Number of cases	5
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[27]	NS

[27] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	None
Best practices information available	No

25.3. Summary of Study

DSFSs were installed at five sites in South Carolina. The style was a fixed-message, speed-activated sign that triggers a flashing beacon when a predetermined speed threshold is exceeded. The context was rural. Three sites were two-lane primary and secondary highways. An additional phase investigated two additional sites that were multilane, divided highways. The posted speed was 45 mph. Measures were taken of the speed 500 ft upstream of the DSFS, at a second location 150-200 ft downstream of the sign, and at a third location 800 ft downstream of the DSFS. The measures were gathered "before" (after installing signs but before turning them on) and "during" (while the signs were turned on). Three before/during measures were made at one site, four before/during measures at a second site, and two before/during measures made at a third site. No data were collected prior to sign installation. Data were not averaged across the sites. Independent variables included: measurement location, treatment condition (DSFS on or off), and upstream approach speed. Dependent variables included: mean speed, 85th percentile speed, percentage of vehicles exceeding the speed limit (3 mph and 10 mph), and distribution of speeds. The major hypotheses were H1B and H2B. The measures of effectiveness used were mean speed, 85th percentile speed, speed compliance and the distribution of speeds. For the first three sites (two-lane highways), the publication reported mean speed changes at the three sensors for each of the three before/during measures at one site, four before/during measures at a second site, and two before/during measures at a third site. It also reported the t-value and the significance level. Speed distributions were also reported combined over the second and third sensors, but in graph rather than tabular form, so exact values are not known. Summary measures were also reported across all data collection sites for reductions in mean speed, 85th percentile speed, and percentage of vehicles exceeding the speed limit (by 3 mph and 10 pmh) (Table 4). For the last two sites (multilane divided highways), average (as well as maximum and minimum) reductions in mean speed, 85th percentile speed, and the percent of drivers exceeding the speed limit were reported. Finally, the distribution of speeds at the two sites at all three stations was reported.

Results. There was a significant reduction in the mean speeds at Station 2 [150 to 200 ft (45.7 to 60.9 m) past the sign] for all of the data sets when the speed-activated sign was on. Results from Station 1 [more than 500 ft (152.4 m) upstream] indicated that there was not a significant reduction in speed from the "control" to the "treatment" condition at the upstream location. The upstream Station 1 was located at such a distance that the speed-activated sign could not be seen. Results from the downstream Station 3 [more than 800 ft (243.8 m) downstream] showed a

significant reduction in the means for all the treatment data sets. The speed-activated sign also caused reductions in 85th-percentile speed and the percentage of vehicles exceeding the speed limit. These data were reported for both the first three sites (two-lane highways) and the latter two sites (multilane divided highways), but statistical significance was mentioned only for the latter two sites. Table 4 depicts the large variation in the ranges of reductions for the first three sites and Table 5 depicts the same information for the last two sites. The authors attribute this to variation in the number of vehicles traveling over the posted speed limit for each period. They posit that that the speed-activated sign was most effective during periods of excessive speeding.

Statistical Analysis. Data were collected to ensure results at a 95 percent-confidence level. A minimum sample size of 97 was determined based on an estimated sample standard deviation of 5.0 mph and a permitted error of 1.0 mph for the mean speed. "Data obtained were assumed to be normally distributed; therefore parametric hypothesis testing was conducted to test for equal means and changes in the percentages of vehicles exceeding the speed limit. The two-sample t-test was used to evaluate the difference in mean speeds, while the z-test for comparing proportions taken from two independent samples was used to test for significant differences in the proportion of vehicles exceeding the speed limit by 3 mph (4.8 km/h) and 10 mph (16.1 km/h) at each station. Each test was conducted to ensure a 95% level of confidence."

25.4. Study Schematic

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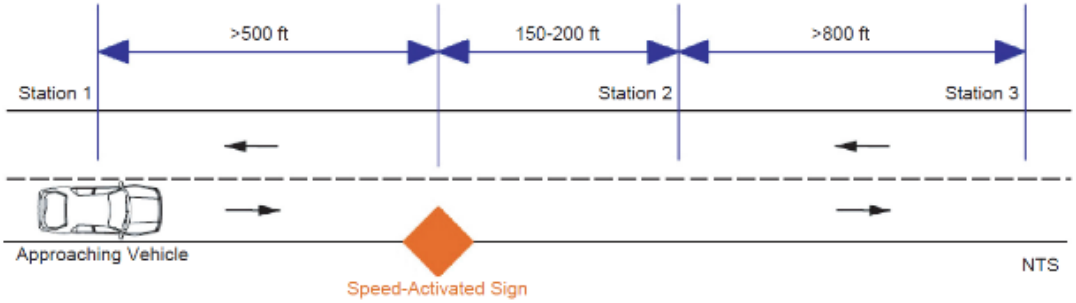

25.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

26. McCoy and Pesti, 2001

26.1. Study Characteristics

Item	Response
Authors	McCoy and Pesti
Title	Smart Work Zone Technology Evaluations: Speed Monitoring Displays and Condition-Responsive, Real-Time Travel Information Systems
Publication year	2001

26.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	NA
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	NA
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded (only for passenger vehicles)

Feature	Study Information
H3: Mean speed	NA
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	55 mph
Sensor positions	Upstream (-250 ft); downstream (750 ft)
Number of sensors	1,0,1
Sensor types	Magnetic
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation (“before” measurements)	58 hours
Time interval between “before” measurements and activation	NS
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[28]	NA
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

26.3. Summary of Study

The article discusses two studies that took place in 1999 and 2000. This review summarizes the 1999 study. The 2000 study is described in a separate review (Pesti and McCoy, 2011), as it is redundant with that article. The 1999 study evaluated three technologies at a work zone on a rural interstate highway in Nebraska. These included a DSFS and two types of portable, condition-responsive, real-time traveler information systems. The DSFS was evaluated in a short-term deployment at a single point on an approach to the work zone.

The speed limit was 55 mph at the DSFS, but it was 65 mph immediately upstream and 75 mph even further upstream. About 58 hours of speed data were collected before the DSFS sign was deployed. Only 7 hours of speed data were collected during the deployment, due to an equipment malfunction. The article did not specify the exact timing of these measurements relative to the deployment of the DSFS. Measures were taken of the mean speed, standard deviation, 85th-percentile speed, 10-mph pace, percentage of speeds in the pace, percentage complying with the speed limit, and mean of highest 15 percent of speeds. Data for passenger and non-passenger vehicles were analyzed separately.

The DSFS displayed the speed via LED, and was located at the outside edge of the left shoulder about 250 feet in advance of the "SPEED LIMIT 55" sign, or about 1,250 feet before the merge taper. Three magnetic imaging sensors were installed in the center of each traffic lane at distances of 1,500 and 500 feet in advance of the merge taper. This is equivalent to 250 feet upstream of the DSFS and 750 feet downstream of the DSFS. Four sets of uncongested flow data were analyzed: passenger cars, daytime; non-passenger cars, daytime; passenger cars, nighttime; and non-passenger cars, nighttime. Independent variables included treatment and vehicle type. Dependent variables were as follows: mean speed, standard deviation, 85th-percentile speed, 10-mph pace, percentage of speeds in the pace, percentage complying with the speed limit, and mean of highest 15 percent of speeds. Hypothesis H2B was evaluated. The article reported data

[28] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

for all seven of the stated dependent variables for the two locations (250 feet upstream and 750 feet downstream), before and during deployment. The article also indicated whether differences were statistically significant.

Results. The DSFS was found to be effective in lowering speeds and increasing the uniformity of speeds. At 500 feet in advance of the merge taper, which was 750 feet downstream from the DSFS, the 85th percentile speed, upper limit of the pace, and mean of the highest 15 percent of speeds were reduced significantly ($\alpha = 0.05$) by about 5 mph, which lowered the values of these parameters to, or below, the speed limit. Its effects on passenger car and truck speeds were similar, increasing speed limit compliance to 90 percent or more. At this location, it was equally effective day and night. However, at 1,500 feet before the taper, which was 250 feet in advance of the DSFS location, its effects were greater at night because of its greater nighttime visibility.

Statistical Analysis. The statistical significance of the differences in these speed parameters before and during the deployment of the DSFS was determined. The t test was used to evaluate the differences between the before and after values of the mean speed, 10-mph pace, and mean of highest 15 percent of speeds. An analysis of covariance was also conducted to account for the effects of traffic volume in the comparison of mean speeds. The binomial proportion test was used to evaluate the statistical significance of differences between the before and after values of the 85th-percentile speed, percentage of speeds in the pace, and percentage complying with the speed limit. The F test was used to check for statistically significant differences between the before and after values of the standard deviation of the speed distribution.

26.4. Study Schematic

See Figure 1 and Figure 2 in article.

26.5. DSFS Graphic

See figure in article.

27. McCoy, Bonneson, and Kollbaum, 1995

27.1. Study Characteristics

Item	Response
Authors	McCoy, Bonneson, and Kollbaum
Title	Speed Reduction Effects of Speed Monitoring Displays With Radar in Work Zones on Interstate Highways
Publication year	1995

27.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	No change
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Arterial
Area type (location)	Rural
Sidewalks present	No
Posted speed	55 mph before the lane taper, 45 mph at start of lane taper (312 ft downstream of the DSFS), and 30 mph in the work zone (downstream of the last speed detector).
Sensor positions	Upstream (-3,691 ft); adjacent (312 ft); downstream (984 ft)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	1 day
Time interval between "before" measurements and activation	1 day
Duration of activation	1 week
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[29]	1 week
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

27.3. Summary of Study

DSFSs were installed at one site in South Dakota, an urban section of interstate, 4-lane (2 on each side), but with a lane merge down to one lane on the study side. The segment was lightly curved with one off-ramp and one on-ramp, but only free flowing traffic was included in the analysis. The posted speeds were 55 mph before the lane taper, 45 mph at start of lane taper (95 m downstream of the DSFS), and 30 mph in the work zone (520 m downstream of the DSFS and 220 m after the last speed detector). Measures were taken of the mean speed and the percentage of vehicles exceeding the speed limit. These measures were taken 1,125 m upstream, 95 m downstream, and 300 m downstream of the DSFS. The measures were gathered before (1 day), and during (1 day of measurement after DSFS had been operating for 7 days). Observations were also made of the time of day and the number of axles. There was only one site, so the data were not averaged over multiple locations. Independent variables were as follows: measurement location, treatment condition, approach speed upstream, time of day, number of axles Dependent variables were as follows: mean speed and percentage of vehicles exceeding the speed limit The major hypotheses were H1B and H2B. The measures of effectiveness were mean speed and percentage of vehicles exceeding the speed limit. The article reported mean speeds and percentage of drivers exceeding the speed limit

Results. The results are as follows for changes in mean speeds. H1B: There was a significant main effect of the DSFS on the mean speed at the DSFS. The least-square mean speed at the DSFS was 4.7 mph less during its activation than before. H2B: There was a significant main effect of the DSFS on the mean speed downstream of the DSFS. The least-square mean speed downstream of the DSFS was 3.8 mph less during its activation than before. At the DSFS and downstream, there was a statistically significant decrease (at the 0.05 significance level) in the percentage of vehicles exceeding the speed limit during DSFS activation as compared to before. There was also a significant main effect of the number of axles at the DSFS and downstream of the DSFS. At the DSFS and downstream, there was a statistically significant decrease (at the

[29] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

0.05 significance level) in the percentage of vehicles exceeding the speed limit during DSFS activation as compared to before.

Statistical Analysis. "An analysis of variance was conducted to determine the statistical significance of the differences in the before and after mean speeds at Stations 2 and 3. In the analysis, time of day and number of axles were used as blocking factors because they were expected to have influenced the vehicle speeds. In general, traffic speeds are lower during periods of higher traffic volumes, and because traffic volume varied throughout the day, time of day was used as a blocking factor in the analysis. The differences in mean speeds observed between the vehicle classes shown in Table 2 indicated that the number of axles may affect vehicle speeds and therefore should be used as a blocking factor. Another factor that would be expected to influence a vehicle's speeds at Stations 2 and 3 was its speed at Station 1. The faster a vehicle is traveling at Station 1, the faster it would be expected to be traveling at Stations 2 and 3. However, it was not possible to accurately track vehicles over the 1,220 m (4,000 ft) between Stations 1 and 2. Therefore, the average speed at Station 1 during the same hour of the time of day when the vehicle's speeds were recorded at Stations 2 and 3 was used as a covariate to account for the possible effect of speed at Station 1. Thus, the effects of time of day, number of axles, and speed at Station 1 were accounted for in the analysis. In addition, all two factor interactions were considered, and those that were not significant were eliminated. The analysis was performed using the General Linear Analysis Procedure of the Statistical Analysis System."

27.4. Study Schematic

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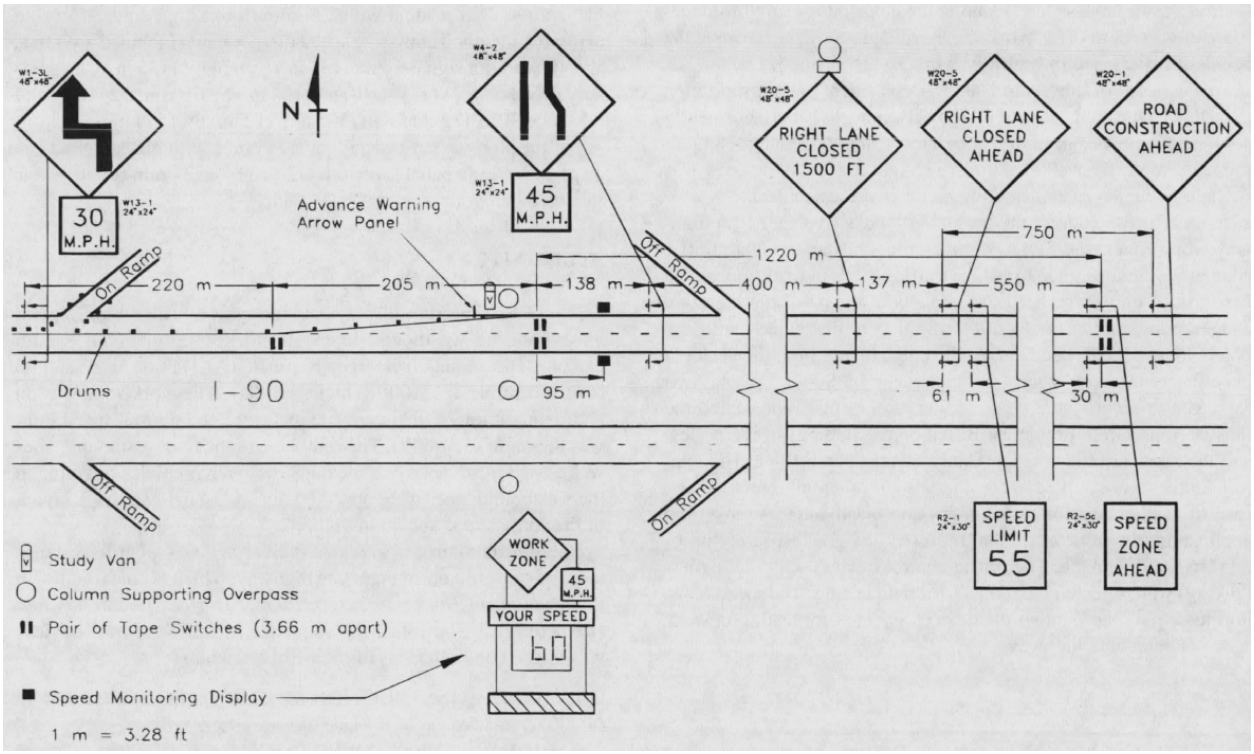
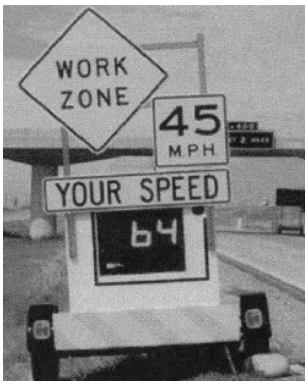


Study site plan

27.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.



28. Medina, Benekohal, Hajbabaie, Wang, and Chitturi, 2009

28.1. Study Characteristics

Item	Response
Authors	Medina, Benekohal, Hajbabaie, Wang, and Chitturi
Title	Downstream Effects of Speed Photo–Radar Enforcement and Other Speed Reduction Treatments on Work zones
Publication year	2009

28.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	NA
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	NA
H2: Mean speed	Mixed
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	NS
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	NS
Sidewalks present	No
Posted speed	55 mph
Sensor positions	Downstream (1.5 miles)
Number of sensors	0,0,1
Sensor types	Video
Types of treatments	DSFS, DSFS with police (lights on), DSFS with police (lights off), police(lights on), police (lights off), speed photo-radar enforcement
Number of relevant sites	3
Number of cases	24
Duration of measurements before activation (“before” measurements)	1 hour
Time interval between “before” measurements and activation	Ranged from 10 minutes to 10 days
Duration of activation	1 hour
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Off peak

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[30]	1 hour
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	lacking standard deviation
Best practices information available	No

28.3. Summary of Study

The effects of automated speed photo–radar enforcement and traditional speed reduction treatments (DSFS, presence of police vehicles with emergency lights on and off, and combinations of the DSFS and police presence) on speed were studied at a location 1.5 miles downstream of the actual treatments.

Three data sets, each including several treatments, were collected in two work zones on Illinois interstate highways. Data Sets 1 and 2 were collected on a 7-mile work zone on I-64 in Illinois near St. Louis, at off-peak morning hours (Data Set 1) and off-peak afternoon hours (Data Set 2). Another data set (Data Set 3) was collected on a 7-mile work zone on I-55 near Joliet, a suburb of Chicago, during off-peak afternoon hours. In both work zones, the posted speed limit was 55 mph, two lanes were open to through traffic, and concrete barriers separated the work area from the traveled lanes.

The downstream effects on the mean speed and degree of speeding of the following six different speed reduction treatments were compared with a base condition without any treatment:

- Mobile DSFS;
- Police vehicle with emergency lights on ("police lights on");
- Police vehicle with emergency lights off ("police lights off ");
- DSFS + police lights on;
- DSFS + police lights off; and
- Speed photo-radar enforcement.

For the speed photo-radar enforcement, data were collected a few weeks after its first deployment and after an extensive public campaign by the Illinois Department of Transportation informing motorists of the use of speed photo-radar enforcement in work zones in the state.

[30] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Video recorders and two markers about 200 feet apart from each other were used to determine vehicles' speed. Similar to the treatment location, the downstream data collection site was located in the work zone, along an approximately level and straight stretch of roadway, and away from ramps and pronounced curves. Data were reported for the general traffic stream and also separately reported for vehicles in free-flow traffic conditions. If the headway between a vehicle and the vehicle in front was more than or equal to 4 seconds, the following vehicle was considered free-flowing. The mean speeds and the speeding percentages were analyzed separately for passenger cars and trucks and for vehicles in the median and in the shoulder lane.

Results. At 1.5 miles downstream, field data consistently showed significant effects for speed photo-radar enforcement. The effects of "DSFS + Police Lights Off" were limited to Data Set 2 on cars in the median (2.7 mph reduction) and shoulder lanes (1.5 mph reduction), and on trucks in median lanes (1.7 mph reduction). The "Police Lights Off" and "DSFS + Police Lights On" treatments did not show any significant effects on mean speed at 1.5 miles downstream.

Statistical Analysis. "For comparing the mean speed of different treatments, 'least significant difference' tests were performed with a confidence level of 90%. This test classifies the mean speeds into groups where means that are not statistically different are grouped together."

28.4. Study Schematic

Not available

28.5. DSFS Graphic

Not available

29. Meyer, 2000

29.1. Study Characteristics

Item	Response
Authors	Meyer
Title	Evaluation of Two Strategies for Improving Safety in Highway Work Zones
Publication year	2000

29.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	60 mph
Sensor positions	Upstream (-1,500 ft,-1,000 ft,-500 ft); Adjacent (0 ft); Downstream (2,600 ft)
Number of sensors	3,1,1
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	2
Duration of measurements before activation ("before" measurements)	1 week
Time interval between "before" measurements and activation	1 week
Duration of activation	NS
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[31]	NS

[31] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	No
Best practices information available	No

29.3. Summary of Study

DSFSs were installed at one site in rural Kansas. The DSFS included "a back-lit dynamic speed display, a standard speed limit sign posted above the display, and a strobe flash, all contained in a trailer mount DSFS." The roadway was a straight segment of highway with four travel lanes (two in each direction) with work zone restricted to two lanes with two-way traffic (eastbound merges to westbound). The posted speed was 60 mph. Measures were taken of the mean speed, the 85th percentile speed, and the percentage of vehicles exceeding the speed limit. Ten sensors were placed around the DSFS (upstream, adjacent, and downstream), but useable data were only obtained from four sites. Data were discussed for two locations – adjacent to the DSFS and a half mile (2,600 ft) downstream. The measures were gathered before and during the time that the DSFS was activated. The "before" set of measurements were taken over the course of one week; the timeframe for the measurements while the DSFS was in place was not specified. Independent variables included treatment, measurement location, vehicle type (cars, trucks), and time of day (night, day). Dependent variables included mean speed, 85th percentile speed, percentage of the sample exceeding the speed limit, and standard deviation. The major hypotheses were H1B and H2B.

Data Reported. Mean speed, percentage of drivers exceeding the speed limit, and speed distribution graphs for baseline, radar drone, and DSFS treatments adjacent to the DSFS and 0.5 mile downstream of the DSFS for both passenger vehicles and trucks were reported.

Results. For H1B, mean speed of passenger cars decreased from 62.3 mph to 59.5 mph. For H2B, mean speed of passenger cars decreased to 61.4 mph (baseline not specified). The percentage of passengers cars speeding dropped from 67 percent to 30 percent at the DSFS, and dropped to 60 percent downstream of the DSFS.

Statistical Analysis. The details of the statistical analysis conducted are not specified, but all reported reductions were statistically significant at a 95 percent confidence level

29.4. Study Schematic

Not provided.

29.5. DSFS Graphic

Not provided.

30. O'Brien and Simpson, 2012

30.1. Study Characteristics

Item	Response
Authors	O'Brien and Simpson
Title	Use of "Your Speed" Changeable Message Signs in School Zones: Experience From North Carolina Safe Routes to School Program
Publication year	2012

30.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O-O-O-O
Safety focus	School zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Collector
Area type (location)	Suburban
Sidewalks present	Yes
Posted speed	25 mph
Sensor positions	Adjacent (0 ft)
Number of sensors	0,1,0
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation ("before" measurements)	1 day
Time interval between "before" measurements and activation	1 day
Duration of activation	1 year
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Peak
Time intervals at which measurements were taken during activation ("during" measurements)[32]	1, 3, 6, 9, and 12 months

[32] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	Yes

30.3. Summary of Study

DSFSs were installed at a site in Greenville, North Carolina. The DSFS was a dynamic speed display sign appearing immediately below the regulatory speed limit sign, showing "Your Speed _____" in amber-lit numerals with a yellow–green color for the sign backing. The context was suburban, on a four-lane road divided by a tree-lined median with unmarked bike lanes, on-street parking, and a sidewalk on both sides through the school zone. The posted speeds were 35 mph when the school zone was inactive and 25 mph when the school zone was active. Measures were taken of the mean speed, the 85th percentile speed, the percentage of vehicles exceeding the speed limit, and the pace speed. These measures were taken at a position adjacent to the DSFS. The team installed DSFS devices and collected data simultaneously on both sides of the street, for opposite directions of travel. So, in effect, there are actually data from two "sites" although they are both at the same cross section. The measures were gathered before (1 day), and during (at 1, 3, 6, 9, and 12 months of cumulative operation).

For each interval, speed data were collected for the duration (approximately 1 hour) of each school time (morning and afternoon) on a given day. In addition, at least 100 speed samples or 1 hour of data collection were obtained in each direction of travel in the morning and afternoon during non–school time on the same day. The non–school time data were collected beginning (and ending) at least 30 minutes after (and before) the school time speed limit was in effect. Speed data were collected on a Tuesday, Wednesday, or Thursday when school was in session (i.e., teacher workdays and early release days were avoided). All attempts were made to collect data under similar weather conditions and from an inconspicuous spot so as not to influence drivers' speeds. Data were not averaged across the sites. Independent variables were as follows: treatment, duration of treatment, school zone status (active or inactive). Dependent variables were as follows: mean speed, 85th percentile speed, percentage of vehicles exceeding the speed limit, and 10 mph pace speed. The major hypothesis was H1B. The publication reported sample size, mean speed, standard deviation, 85th percentile speed, percentage of vehicles exceeding the speed limit, and 10 mph pace speed for each site, measurement period, and school zone status (i.e. school zone inactive versus active).

Results. For data collected while the school zone was active, significant findings of this study include a 3.0 mph ($p < .0001$) to 4.5 mph ($p < .0001$) reduction in speed sustained over a 12-month period. Also, for data collected while the school zone was active, the difference between the average speed and 85th percentile speed, which can be a rough indicator of speed dispersion,

decreased for both directions of travel, with the widest spread (5.3 mph) observed before and the narrowest spread (2.5 mph) observed 6 months after installation of the signs in the southbound direction of travel. Standard deviation results also indicate that speed dispersion was significantly reduced. Data collected while the school zone was not active served as a control group. No significant variation in speed measures were expected when before and during data were compared for this group, primarily because the DSFS signs were not operational when the school zone was inactive. However, the actual results showed that there was some variation. For example, there was a sharp reduction in northbound speeds one month after installation of the DSFS devices observed when the school zone was inactive. This suggests that other factors may be at work. The authors note that other education and outreach activities conducted through the Safe Routes to School project may have augmented the observed effectiveness.

Statistical Analysis. "The speed measurements generally followed a normal distribution; therefore, data were analyzed by using methods that assume normality. Average speeds before and after installation of the "Your Speed" signs were compared by using two-sided unpaired t-tests. Differences in standard deviations before and after installation were assessed by using f-tests. Differences in the 85th percentile speed, pace speeds, and percentages of drivers in the pace speeds were not tested directly because these are determined by the mean and standard deviation. P-values less than .05 were considered statistically significant."

30.4. Study Schematic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

30.5. DSFS Graphic

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3:00 - 4:00 PM
YOUR
SPEED

31. Pesti and McCoy, 2011

31.1. Study Characteristics

Item	Response
Authors	Pesti and McCoy
Title	Long-Term Effectiveness of Speed Monitoring Displays in Work Zones on Rural Interstate Highways
Publication year	2011

31.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	na
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	B
H1: Mean speed	na
H1: 85th percentile speed	na
H1: Percentage of drivers over speed limit	na
H1: Distribution of speed	na
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	Significant reduction recorded

Feature	Study Information
H3: 85th percentile speed	Reduction recorded
H3: Percentage of drivers over speed limit	Significant reduction recorded
H3: Distribution of speed	No change
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	55 mph
Sensor positions	Upstream (-1,150 ft); downstream (1,000 ft from first DSFS, 1,000 ft from second DSFS, and adjacent to third DSFS)
Number of sensors	1,0,3
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	2
Duration of measurements before activation (“before” measurements)	4 days
Time interval between “before” measurements and activation	4 days
Duration of activation	5 weeks
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[33]	1,2,3,4, and 5 weeks
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	1 week
Duration of "after" measurements	NS
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

31.3. Summary of Study

Three DSFSs were installed on a 2.7-mile stretch of roadway in between two work zones on I-80, a rural freeway near Lincoln, Nebraska. The effectiveness of the system was studied over 5 weeks. The normal speed limit on I-80 is 75 mph, but the speed limit in the study area was 55 mph, due to the fact that it was a short segment in between two work zones.

Traffic speeds were measured once before DSFS deployment, five times during the 5-week deployment, and once after removal of the DSFS. The before studies were conducted four days before the DSFS were deployed. The DSFS were operated continuously for the next five weeks, during which traffic speeds were measured, once each week at one-week intervals. Finally, one week after the removal of the DSFS, another set of speed measurements was taken to determine if there were any residual speed-reduction effects of the system.

All measurements took place on the same day of the week, during approximately the same time period of the day, and under very similar traffic and environmental conditions (i.e., comparable traffic volumes, dry weather, and dry pavement). Measures were taken of the mean speed, 85th percentile speed, standard deviation of speeds, the percentage of vehicles complying with the speed limit, percentage complying with the speed limit plus 5 mph, and percentage complying with the speed limit plus 10 mph. Volume and truck percentages were also recorded.

The speed data were collected with LIDAR sensors, capable of measuring the speed of vehicles with an accuracy of ±1 mph. Vehicle speeds were measured at four locations: (1) 350 m (1,150 ft) upstream of the first DSFS where vehicles entered the study area, (2) approximately 305 m (1,000 ft) downstream of the first DSFS, (3) approximately 305 m (1,000 ft) downstream of the second DSFS, and (4) at the beginning of the lane closure taper where vehicles passed the third DSFS. Data were analyzed for each location. All DSFS displayed the speed of approaching vehicles via LED.

[33] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Independent variables were as follows: treatment and vehicle type. Dependent variables were as follows: mean speed, 85th percentile speed, standard deviation, the percentage of vehicles complying with the speed limit, percentage complying with the speed limit plus 5 mph, and percentage complying with the speed limit plus 10 mph. Hypotheses included: H1B, H2B, and H3B.

The article reported data for all six of the stated dependent variables for three locations (each just downstream of one of three DSFS), and for seven different times. The times included: before (4 days before deployment), during (at 1,2,3,4, and 5 weeks of deployment) and after (1 week after removal). The article also indicated whether differences were statistically significant.

Results. The results indicate an improvement in all measures of effectiveness at each observation point just downstream of the DSFS devices during their 5-week deployment. The improvement was about a 3- to 4-mph reduction in mean speed, 2- to 7-mph reduction in 85th percentile speed, and about a 20- to 40-point increase in the percentage of vehicles complying with the speed limit and the 60-mph speed threshold. As expected, much smaller changes were observed upstream of the first DSFS. Statistically significant improvements in speed parameters and speed-limit compliance were observed at the measurement points downstream of the first two DSFS. The improvement in standard deviation and some compliance percentages were not statistically significant at the third DSFS. Greater speed reductions and compliance increases were observed for passenger cars than for other vehicles. H3: One week after the removal of the DSFS, there were still statistically significant speed reductions and compliance increases, although they were less than during the deployment.

Statistical Analysis. The statistical significance of the differences in the measures of effectiveness corresponding to the periods before, during, and after the use of the DSFS was determined. The t-test was used to evaluate the differences in mean speeds. The binomial proportion test was used to evaluate the statistical significance of differences in the 85th-percentile speeds, and the percentages complying with the speed limit and the speed thresholds of 5 and 10 mph above the speed limit. The F-test was used to check for statistically significant differences in the standard deviations of the speed distribution.

31.4. Study Schematic

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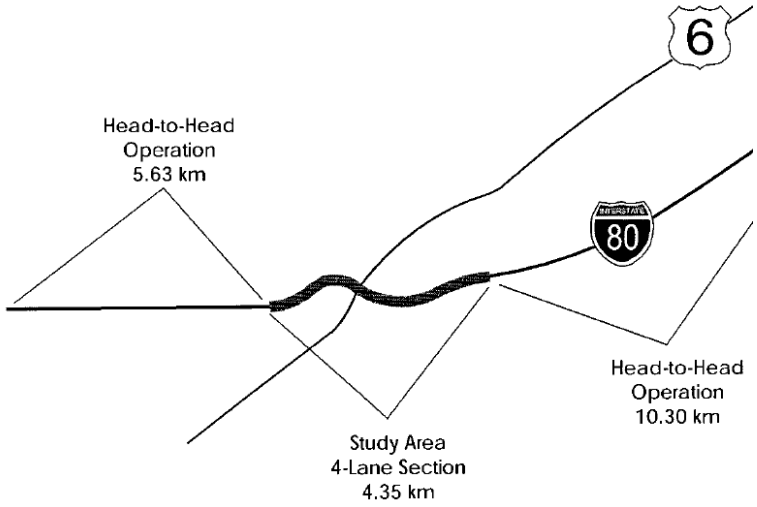
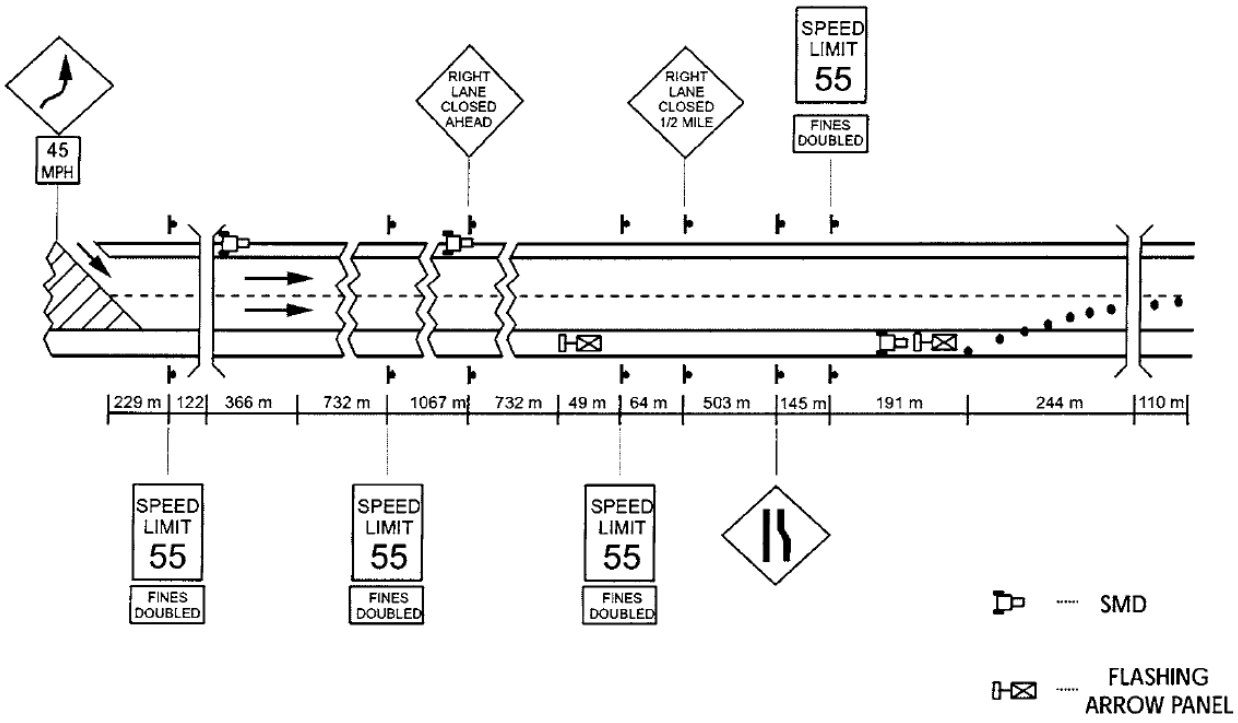


Location of study site



Traffic control plan at study sight (1 mi = 1.16 km)

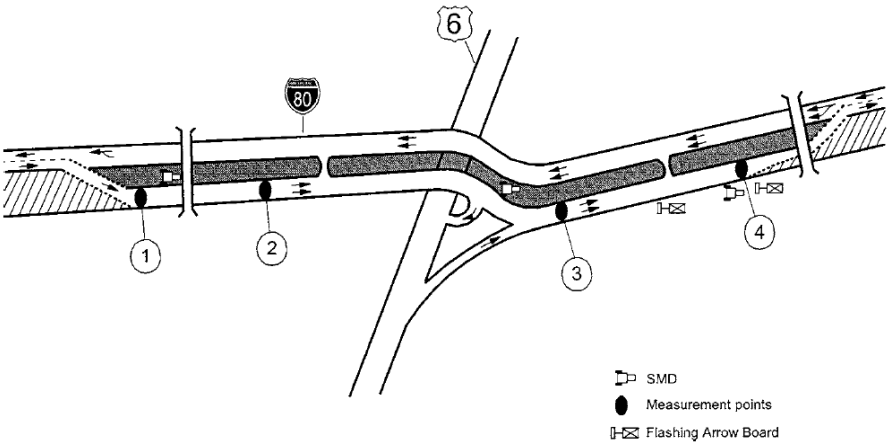


FIGURE 5 Locations of speed measurements.

Locations of speed measurements

31.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

32. Reddy, Datta, Savolainen, and Pinapaka, 2008

32.1. Study Characteristics

Item	Response
Authors	Reddy, Datta, Savolainen, and Pinapaka
Title	Evaluation of Innovative Safety Treatments: A Study of the Effectiveness of Motorist Awareness System in Construction Work Zones
Publication year	2008

32.2. Study Features

Feature	Study Information
Experimental design	O-X-O* (see summary)
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	na
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Significant reduction recorded
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Significant reduction recorded
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	Yes
Mobile DSFS units	Yes
Roadway type	Freeway
Area type (location)	Multiple
Sidewalks present	No
Posted speed	70 mph
Sensor positions	Upstream (NS); adjacent (NS); downstream (NS)
Number of sensors	1,1,1
Sensor types	Radar
Types of treatments	DSFS in combination with changeable message sign and flashing speed limit sign; police enforcement
Number of relevant sites	2
Number of cases	2
Duration of measurements before activation (“before” measurements)	Multiple
Time interval between “before” measurements and activation	Multiple
Duration of activation	Multiple
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[34]	Multiple
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	Multiple
Duration of "after" measurements	Multiple
Meta-analysis data available	Yes
Caveats	DSFS Not evaluated in isolation; distances of Sensors from DSFS NS
Best practices information available	No

32.3. Summary of Study

This study sought to measure the effectiveness of a group of interventions that collectively comprise the Florida Department of Transportation Motorist Awareness System (MAS). The MAS is intended to reduce travel speeds through work zones. The MAS includes DSFSs, but it also includes additional portable changeable message signs and regulatory speed limit signs (with flashers) to alert motorists of work zone activities. The study evaluated the effectiveness of the MAS overall, but did not evaluate the effectiveness of the DSFS as an individual component. The study also investigated the additional impact of supplementary police enforcement.

The study investigated construction projects on two segments of Florida interstate highways: a suburban section of I-10 in Baker County, and a rural section of I-95 in Flagler County. Both sites were four lane-divided freeways with 70 mph posted speed limits prior to the work zones, although I-95 has three travel lanes in one direction at some locations. The speed limit in the work zone on I-10 was 60 mph. For the I-95 locations, the speed limit in the work zone was 70 mph for the control studies and either 55 mph or 60 mph for the treatment studies. This appears to be a flaw of the study for that location, if the speed limit for the control condition truly differed from the treatment condition. The authors did not address this in the paper.

Researchers indicated that the study used a "comparative parallel" evaluation methodology. In other words, this study did not involve the common "before" (pre-intervention), "during" (while the treatment is in place), and "after" (following the removal of the treatment) pattern observed in other studies. Instead, the control and treatment conditions occurred in an intermittent and alternating temporal pattern. The I-10 observations spanned two months, whereas the I-95 observations spanned two years. Each individual observation period was one to two hours in duration, and there were 3-11 observation periods for the I-10 conditions and 5-16 observation periods for the I-95 conditions.

[34] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

The work zone changed positions as work progressed. Thus, researchers were able to collect data at similar locations with and without the treatment condition, but not necessarily at the identical locations. The researchers noted that road geometries, traffic, and weather conditions were quite similar along the study sections, making it possible to compare the test and control data collected at these sites. Speed data were collected for the control condition and the test condition at various times of the day and week. The researchers did conduct a suite of statistical tests to understand the variation in and across observations/locations.

Speeds were collected using radar at three relative locations (upstream, in the work zone, and downstream). However, the exact distance of those locations from the DSFS was not specified in the article. Measures were taken of the mean speeds, 85th percentile speeds, percent of speeding motorists, and variability of the speed distribution. Independent variables were as follows: presence or absence of the MAS treatment (including DSFS), location (upstream, in, or downstream of the work zone), and presence or absence of police enforcement. Dependent variables were as follows: mean speeds, 85th percentile speeds, percent of speeding motorists, and variability of the speed distribution. The major hypotheses evaluated were H1B and H2B.

The article reported sample size, mean speeds, 85th percentile speeds, percent of speeding motorists, and variability of the speed distribution for each treatment condition at each location.

Results. Overall, the MAS was effective in reducing vehicular speeds through construction work zones. Targeted supplementary police enforcement resulted in additional speed reductions. The MAS decreased the proportion of motorists traveling over the posted speed limit.

- Travel speeds, both the mean and 85th percentile speeds, were consistently lower at the locations in the work zones where the MAS was used in comparison to the control. The implementation of the MAS along I-10 reduced average speeds by an average of 1.5 miles per hour in comparison to the control. Combining MAS with enforcement resulted in additional reduction in mean speeds by 3 to 4 miles per hour in comparison to the control.
- The combination of the MAS with enforcement was also shown to decrease speeds in comparison to the control with enforcement along I-95. In general, speeds in the work zone were reduced by an average of 4 to 5 miles per hour.
- The variability of travel speeds along I-10 in the work zone decreased when MAS was used in comparison to the control.
- The proportions of drivers speeding in and near the end of the work zones were also substantially reduced when the MAS was used in comparison to the control under all scenarios. Further, combining MAS with enforcement produced more pronounced reductions both in and near the end of the work zone.

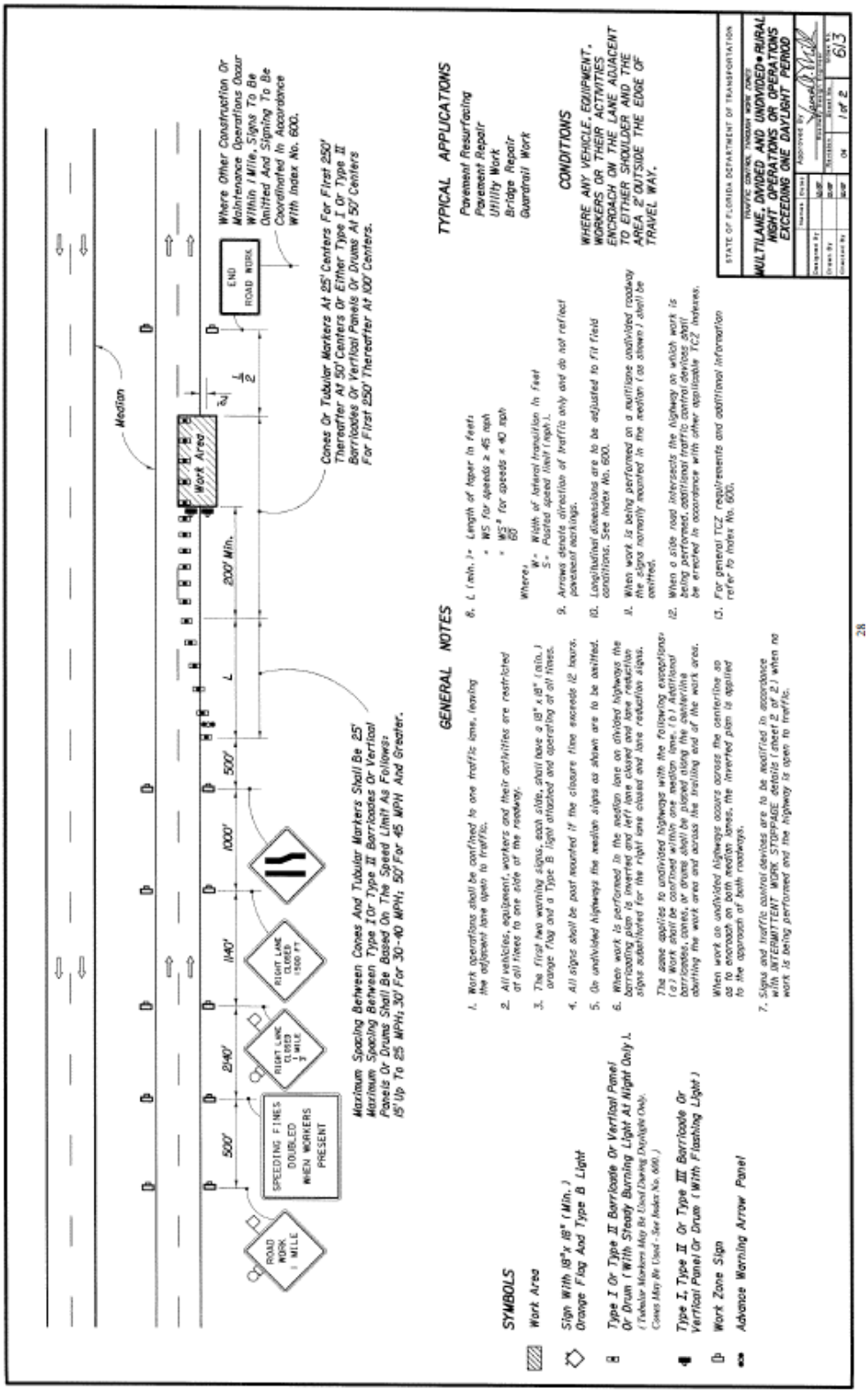
Statistical Analysis. "A number of statistical tests were conducted to determine whether the changes observed in the measures of effectiveness are attributable to the use of the motorist awareness system or simply due to chance. Statistical tests that were conducted to test the effectiveness include:

- One-Sample Kolmogorov-Smirnov Test – to determine if the speed distributions are normally distributed
- F-Test – to determine if the variances are equal between the test and control groups
- Student's t-Test and analysis of variance to determine if differences between mean speed and 85th percentile speed are statistically significant
- Z-Test – to determine if differences between the proportion of vehicles speeding are statistically significant"

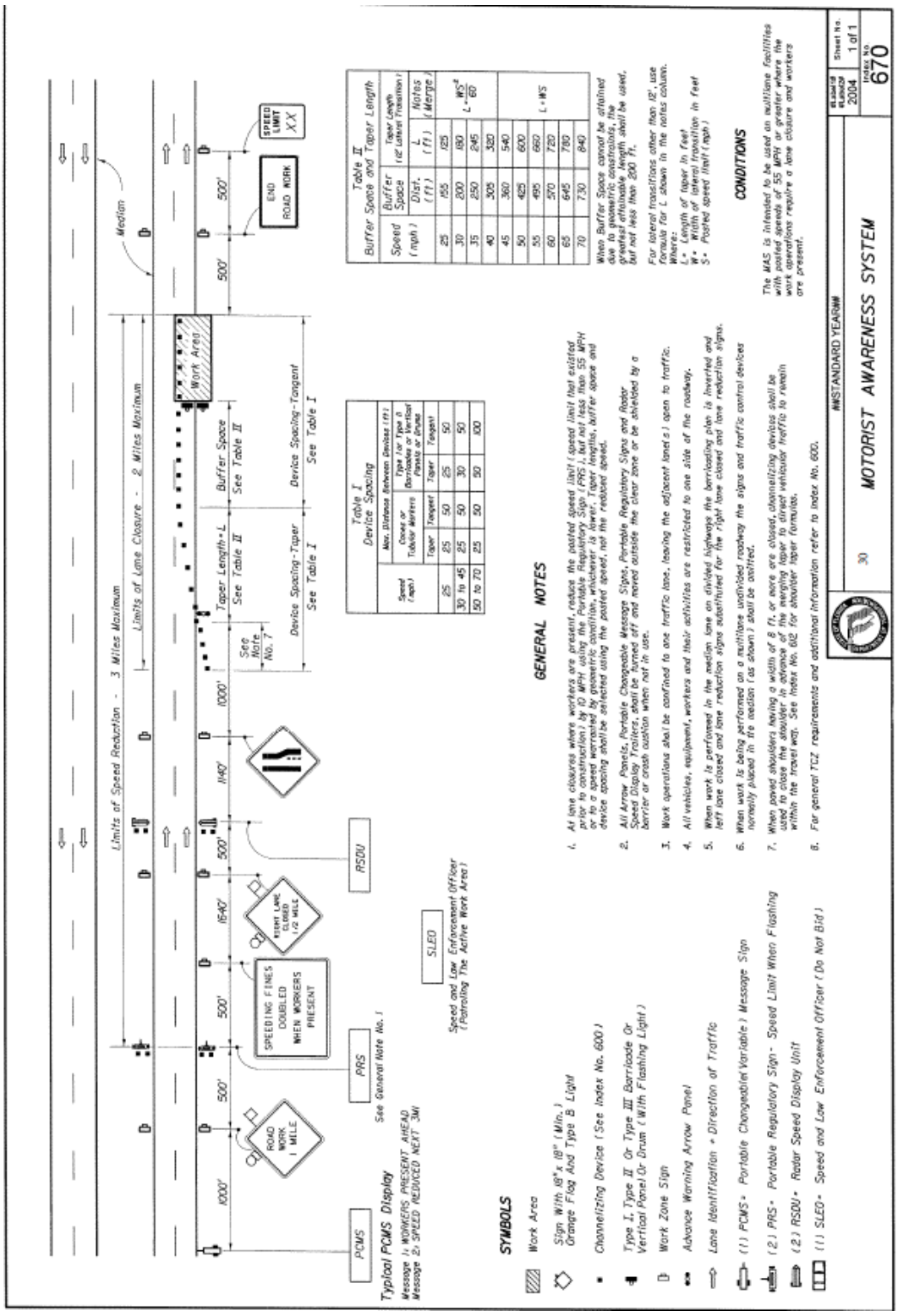
32.4. Study Schematic

Images courtesy of the Florida Department of Transportation.

Control condition



Treatment condition



32.5. DSFS Graphic

Not provided.

33. Roberts and Smaglik, 2012

33.1. Study Characteristics

Item	Response
Authors	Roberts and Smaglik
Title	Driver Feedback on Monetary Penalty and Its Impact on Work Zone Speed
Publication year	2012

33.2. Study Features

Feature	Study Information
Experimental design	O-X-X-O
Safety focus	Work zone
Graphic of DSFS available	No
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	A
Hypothesis 2 (H2) level	A
Hypothesis 3 (H3) level	A
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded (only for display showing fine in addition to speed)
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Significant reduction recorded

Feature	Study Information
H3: 85th percentile speed	Significant reduction recorded (only for display showing fine in addition to speed)
H3: Percentage of drivers over speed limit	Reduction recorded for H3A, but for H3A' there was no change for the speed display only and an increase for the speed+fine display
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	Yes
Roadway type	Collector
Area type (location)	Rural
Sidewalks present	No
Posted speed	35 mph
Sensor positions	Upstream (-2,088 ft); adjacent (-178 ft); downstream (792 ft)
Number of sensors	1,1,1
Sensor types	Pneumatic
Types of treatments	DSFS (displaying speed and fine)
Number of relevant sites	1
Number of cases	2
Duration of measurements before activation (“before” measurements)	1 week
Time interval between “before” measurements and activation	0 days
Duration of activation	1-2 weeks
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during	NS

Feature	Study Information
activation ("during" measurements)[35]	
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	12 hours
Duration of "after" measurements	4 days
Meta-analysis data available	Yes
Caveats	Flashing DSFS additionally displayed fine $$ information and was deployed in the same location the week following the standard DSFS.
Best practices information available	No

33.3. Summary of Study

A CMSR was installed at one site in Arizona. The context was a work zone on a rural state highway. Four sets of measurements were taken:

1. Before the sign was activated, with only standard work zone signage;
2. While the sign was active and displayed the driver's speed;
3. While the sign was active and alternated displaying the driver's speed with a message showing their possible fine for speeding; and
4. After the sign was removed, with only standard work zone signage.

Measurements were taken over 6 weeks, with each data set lasting 4 to 13 days. Data was taken at all times of day, but restricting to free flow traffic with at least 5 seconds headway. Measurements were taken with pneumatic sensors at three locations: upstream (-2,088 ft); adjacent (-178 ft); and downstream (792 ft) at a point in the work zone where speed should be slowed. The posted speed was 50 mph upstream, and 35 mph at the CMSR and downstream (in the work zone). Measures were taken of mean speed, median speed, 85th percentile speed, percentage of drivers above the speed limit (in 5mph brackets), and sample size after data cleaning.

Data Reported. The article reported mean speed, median speed, 85th percentile speed, percentage of drivers above the speed limit (in 5mph brackets), and whether changes were statistically significant for each sensor location, time period, and treatment. Sample size and standard deviation were also provided.

Results. For H1, mean speed, 85th percentile speed, and percentage of drivers speeding in each bracket dropped significantly for both treatments, except the 60+ mph speed bracket for the

[35] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Speed Only treatment (no significant change). For H2, mean speed, 85th percentile speed, and percentage of drivers speeding in each bracket dropped significantly for both treatments relative to upstream, relative to at the CMSR, and relative to before the treatments, with the exception of comparing downstream 85th percentile speed to speed at the CMSR for the Speed Only treatment (no significant change there). For H3, mean speed decreased significantly relative to upstream, relative to at the CMSR (both treatments), and relative to before the treatments. The 85th percentile speed decreased significantly relative to upstream, relative to at the CMSR (Speed and Fine treatment, no change relative to Speed Only treatment), and relative to before the treatments. The percentage of drivers over the speed limit, for all brackets, decreased significantly relative to before the treatments, increased significantly relative to during the Speed and Fine treatment, and had no significant change relative to the Speed Only treatment. Compared to upstream, after, the +5 mph and +10 mph brackets increased significantly and the other three brackets decreased significantly.

Statistical Analysis. Not described.

33.4. Study Schematic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

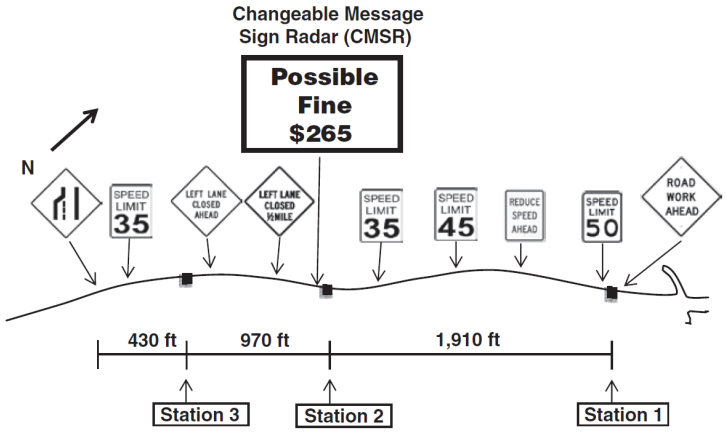


FIGURE 1 Locations of data collection stations.

Locations of data collection stations

33.5. DSFS Graphic

DSFS model cited in paper, image sourced from Ver-Mac company website: www.ver-mac.com/en/products/series/serie/message-signs/product/portable-changeable-message-sign-pcms/1

34. Saito and Ash, 2005

34.1. Study Characteristics

Item	Response
Authors	Saito and Ash
Title	Speed Monitoring Displays: Increasing Speed Limit Compliance in Reduced Speed School Zones
Publication year	2005

34.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	School zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded (5 of 8 sites)
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	NA
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	No
Roadway type	Local
Area type (location)	NS
Sidewalks present	NS
Posted speed	20 mph
Sensor positions	Adjacent (NS)
Number of sensors	0,2,0
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	8
Number of cases	8
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	3-6 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[36]	3-6 months. Some sites also had measurements after 4 or 8 weeks.

[36] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	No
Best practices information available	No

34.3. Summary of Study

DSFSs were installed at eight sites in Utah. The style of DSFS was a speed measurement display (see picture below). It was not clear from the study whether sites were rural or urban. The roadway was a straight segment, paved, with two-way traffic. There were two, four, or six lanes depending on the site. The posted speed was 20 mph. Measures were taken of the mean speed, 85th percentile speed, the percentage of vehicles exceeding the speed limit, the 10 mph pace, and the percent of vehicles in the 10 mph pace. The measures were gathered adjacent to the DSFS before and during the time that the DSFS was activated. The duration that the DSFS had been in place when measurements were taken ranged from 4 weeks to 6 months, partially deliberately and partially due to equipment malfunctions. There were no measurements after the DSFS was removed. Each set of measurements was taken over a 4-day weekday period, Monday to Thursday. Measurements were only taken when the school zone was in effect, but at various times from 7:30 a.m. to 4 p.m.. The time of day was tracked. Data were not averaged across the sites. Independent variables included treatment, duration of treatment, time of day, and number of lanes. Dependent variables included mean speed; 85th percentile speed; 10 mph pace; percent of vehicles exceeding the speed limit; and percent of vehicles in the 10 mph pace. The major hypothesis was H1B. No statistical analysis was described to evaluate the hypotheses, only the raw data. However, results that were significant "based on a normal approximation test at a 95% confidence level" are identified.

Data Reported. Mean speed, 85th percentile speed, the percentage of vehicles exceeding the speed limit, the 10mph pace, the percent of vehicles in the 10 mph pace, the sample size, and standard deviation for each site.

Results. Five sites showed a statistically significant decrease in mean speed for at least one set of measurements (out of two or three taken at different times of day). The significant decreases in mean speed ranged from .08 to 3.45, but most were between 1 and 3mph. Three sites showed a statistically significant *increase* in mean speed ranging from .55 to 2.3mph. There were no statistically signficant changes identified in the other measures, but they generally changed in the same direction as the mean speed with less magnitude.

Statistical Analysis. No statistical analyis was described, but changes to mean speed that are statistically significant "based on a normal approximation test at a 95% confidence level" are identified.

34.4. Study Schematic

Not provided.

34.5. DSFS Graphic

Images courtesy of the authors.

35. Santiago-Chaparro, Chitturi, Bill, and Noyce, 2011

35.1. Study Characteristics

Item	Response
Authors	Santiago-Chaparro, Chitturi, Bill, and Noyce
Title	Spatial Effectiveness of Speed Feedback Signs
Publication year	2011

35.2. Study Features

Feature	Study Information
Experimental design	X-O
Safety focus	NS
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	C
Hypothesis 2 (H2) level	C
Hypothesis 3 (H3) level	na
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Nothing reported
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Yes
Mobile DSFS units	NS
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	NS
Sensor positions	Upstream (1,125 ft) through downstream (900 ft)
Number of sensors	3
Sensor types	Radar
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	NA
Time interval between "before" measurements and activation	NA
Duration of activation	18 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Off peak
Time intervals at which measurements were taken during activation ("during" measurements)[37]	12 months

[37] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	None
Best practices information available	No

35.3. Summary of Study

Data were collected on State Highway 164, a two-lane rural highway in Washington County, Wisconsin, with a posted speed limit of 55 miles per hour. Speeds were monitored upstream and downstream of the DSFS, which was installed for an 18-month period. Incidentally, DSFS were also installed concurrently at three other locations on Highway 164 to complement periodic police enforcement. Researchers attempted to assess the spatial effectiveness of the DSFS by using radar to record the speed trajectories of vehicles from 1,125 feet upstream to 900 feet downstream of the DSFS. In addition, video data were collected. Trajectories upstream of the sign were monitored from 11 a.m. to 1 p.m., while downstream trajectories were monitored from 2 p.m. to 4 p.m., therefore avoiding the morning and afternoon peak periods. Both were measured on the same day, 1 year after the initial DSFS installation.

Trajectories were obtained only for free-flowing vehicles. A free-flowing vehicle was defined as one that maintained at least an eight second gap to the leading vehicle. The change in vehicle speed was determined, as well as the corresponding speed profile when the vehicle approached the DSFS or receded from the DSFS. Change in speed upstream of the DSFS was defined as the difference between the first speed recorded and the speed at the end of the section. Accordingly, change in speed downstream of the DSFS was defined as the difference between the speed at the DSFS and the speed at the end of the section. A binary logistic regression model was developed to predict the probability of speed reduction as a function of initial speed.

The article only reported changes in speeds from the upstream to the adjacent and from the adjacent to the downstream. It did not report the actual speeds. Although the article reported changes in speeds, it did not report whether or not they were statistically significant.

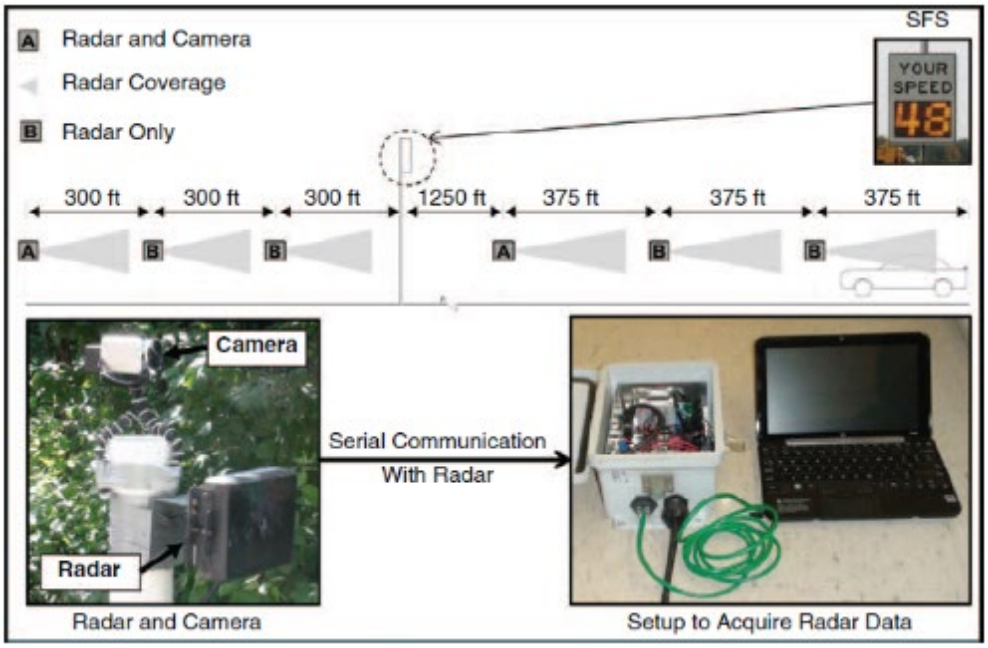
Results. As expected, the model revealed that the greater the speeding, the higher was the probability of a vehicle reducing speed. Even drivers who were not speeding reduced their speed when approaching the DSFS, although with a lesser probability. The speed reductions were most apparent 1,200 to 1,400 feet upstream of the DSFS. Downstream, speeds started to increase again 300 to 500 feet past the DSFS; nonetheless, within 800 feet downstream of the sign, 49 percent (n=23) of the vehicles had reduced their speeds by at least 1.0 mile per hour.

Statistical Analysis. A binary logistic regression model was developed to predict the probability of speed reduction as a function of initial speed.

35.4. Study Schematic

Images courtesy of the authors and reproduced with permission of the Transportation Research Board.

Stud location site at STH 164



35.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

36. Sarasua, Ogle, Davis, and Chowdhury, 2006

36.1. Study Characteristics

Item	Response
Authors	Sarasua, Ogle,Davis, and Chowdhury
Title	Better Management of Speed Control in Work Zones
Publication year	2006

36.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Multiple
DSFS speed lighting	Yes
DSFS flashes (speed or other)	Multiple
Mobile DSFS units	Multiple
Roadway type	Freeway
Area type (location)	NS
Sidewalks present	NS
Posted speed	35-65 mph
Sensor positions	Upstream (at least -500 ft), adjacent (150-200 ft) and downstream (at least 1,200 ft)
Number of sensors	1,1,1
Sensor types	Multiple (laser, radar, and video)
Types of treatments	Changeable message sign with radar, speed monitoring display, police enforcement, speed activated blinker
Number of relevant sites	17
Number of cases	17
Duration of measurements before activation (“before” measurements)	1 hour
Time interval between “before” measurements and activation	NS
Duration of activation	1 hour
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[38]	
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	Graphical only
Best practices information available	No

36.3. Summary of Study

This study evaluated the effectiveness of a variety of devices and strategies for reducing vehicle speeds in work zones on highways in South Carolina. The devices selected were as follows, with bold font to emphasize those relevant to this literature review.

- Drone radar
- Portable rumble strips
- **Changeable message sign with radar.** Message panel measured 126 inches wide by 76 inches high. It displayed a default message unless cars were speeding, in which case it displayed a warning to slow down, as shown in the four-stage sequence in Figure 4.4, pasted below.
- **DSFS with changeable message sign.** Equipped with a programmable two-line message panel capable of displaying five 12-inch characters per line. Speeds were displayed below the lines of text by two 24-inch digits. For this study, it asked drivers to "stay alert" unless they were speeding, in which case it alternated "watch speed" with either "you are speeding" or "fines ahead," depending on whether there was law enforcement. It was mounted on the rear of a van.
- **Novel speed activated sign** designed by the researchers: A 4-foot by 4-foot corrugated plastic reflective sign with 6-inch lettering read "YOU ARE SPEEDING IF FLASHING," with a flashing light on top.

Some of the devices were also studied in combination with police enforcement:

- **Marked enforcement:** The marked police vehicle remained stationary throughout the data collection period 500 feet from the sign. The police officer was in the vehicle, but did not issue any tickets.

[38] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

- **Unmarked enforcement:** The unmarked police vehicle monitored speeds and actively ticketed vehicles. The sign displayed "fines ahead" to speeding vehicles.

The typical data collection was one hour for each condition, both with and without the treatment implemented. Each time researchers made sure to collect the minimum sample size necessary to report results at a 95% level of confidence, which they estimated as 96. Data were collected at up to three stations in each work zone studied: upstream (using laser), adjacent (using radar or video), and downstream (using radar or video). The exact position of each sensor varied for each work site, but in general, the upstream sensors were at least 500 ft upstream of the treatment, the adjacent sensors were about 150-200 ft downstream of it, and the downstream sensors were at least an additional 800 ft downstream. In most cases, speed data were collected for two conditions—one without any countermeasure and one with a countermeasure. Data collectors with the radar units attempted to hide behind vegetation and roadside structures to avoid being seen so as not to skew or bias the data. Data were only collected for platoon leaders, so speeds could be considered free flow.

The data collection sites and the evaluated measures at each site are summarized in the study. The sites relevant to this analysis include the following.

Construction Sites:

- I-585, speed limit 45 mph, tested drone radar and the changeable message sign with radar
- SC Route 72 in Laurens County, tested drone radar, speed activated sign, and changeable message sign with radar
- SC Route 290 in Spartanburg County, tested speed activated sign and changeable message sign with radar
- SC Route 101 in Spartanburg County, tested changeable message sign with radar, the speed activated sign, and the speed monitoring display with changeable message sign.
- SC Route 219 in Newberry, speed limit 45 mph, tested speed activated sign
- US Route 278 in Hilton Head, speed limit 45 mph, tested dual speed activated signs and the speed monitoring display with changeable message sign
- SC Route 121 in Newberry County, speed limit 45 mph, tested and the speed monitoring display with changeable message sign
- SC Route 295, speed limit 45 mph, tested and the speed monitoring display with changeable message sign in conjunction with police enforcement
- SC Route 292, speed limit 45 mph, tested and the speed monitoring display with changeable message sign in conjunction with police enforcement

Maintenance Work Sites:

- US Highway 72 in Abbeville County, tested speed monitoring display with changeable message sign
- US Highway 123/76 in Pickens County, speed limit 35 mph, tested modified speed-activated sign setup
- US Highway 123 in Pickens County, tested speed monitoring display with changeable message sign

The measures of effectiveness were mean speed, 85th percentile speed, and the percent of drivers exceeding the speed limit. The hypotheses investigated were H1B and H2B.

The publication presented summary data on mean speeds, 85th percentile speeds, and the percent of speeders, but only in graphical format, in the form of histograms of speed observations and other similar graphics.

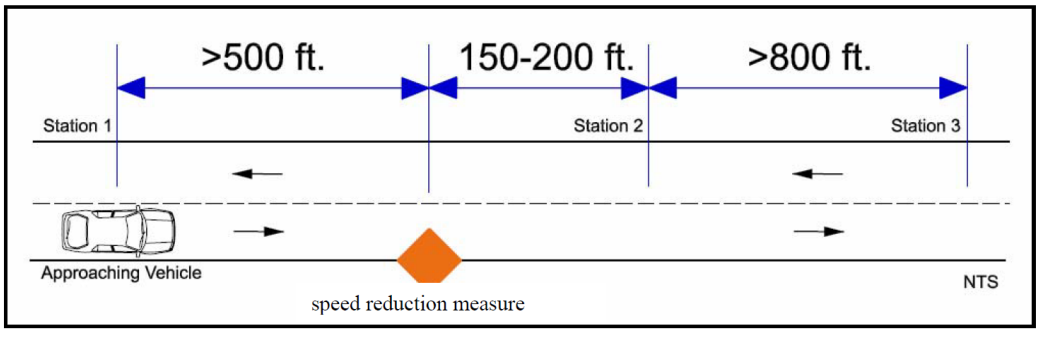
Results. Researchers noted that the results of the analysis show that all of the speed control devices studied during this project have the capability of lowering speeds.

- **Changeable message sign:** All four sites showed significant reductions in mean speeds adjacent to the sign for all of the message sequences with the exception of only one message sequence. It also produced a significant reduction in vehicles exceeding the speed limit by more than 5 mph at all sites and in vehicles exceeding it by more than 10 mph at almost all sites.
- **Speed activated sign:** Showed a significant reduction in the mean speeds adjacent to the sign for nearly all of the data sets at the six sites when the speed-activated sign was on. Produced a significant reduction in vehicles exceeding the speed limit.
- **Speed monitoring display with changeable message sign**: Five of five construction sites showed a significant reduction in mean speeds between the upstream and downstream locations and a significant reduction in the percent of vehicles exceeding the speed limit by five mph. However, the two maintenance sites did not show significant reductions. The speed display coupled with enforcement did not produce results much different from the display-only treatment.

Statistical Analysis. "Sufficient data were collected to ensure a confidence level of 95%. Researchers assumed that the data followed the normal distribution. Based on this assumption, they used parametric hypothesis testing to test for equal means (two-sample t-test) and the percentage of vehicles exceeding the speed limit (z-statistic). They used non-parametric testing to compare the 85th percentile speeds."

36.4. Study Schematic

Image courtesy of the authors.



Typical Layout for Data Collection

36.5. DSFS Graphic

Images courtesy of the authors.

Silent Messenger Portable CMR

Default Sequence:	STAY ALERT →	WORK ZONE
Sequence 1:	YOU ARE SPEEDING →	SLOW DOWN
Sequence 2:	YOUR SPEED IS ___ MPH →	SLOW DOWN
Sequence 3:	YOUR SPEED ___ MPH →	THANKS FOR NOT SPEEDING
	YOUR SPEED ___ MPH →	SLOW DOWN
Sequence 4:	YOU ARE SPEEDING →	MINIMUM FINE $200

Default and Radar Activated Sequences

SMD with CMS

37. Schoenecker, Sandberg, Sebastian, and Soler, 2008

37.1. Study Characteristics

Item	Response
Authors	Schoenecker, Sandberg, Sebastian, and Soler
Title	Long-Term Effectiveness of Dynamic Speed Monitoring Displays for Speed Management at Speed Limit Transitions
Publication year	2008

37.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	NS
Classes of vehicles included	NS
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	No
Mobile DSFS units	No
Roadway type	Collector
Area type (location)	Rural to urban transition
Sidewalks present	NS
Posted speed	Multiple
Sensor positions	Upstream (-1/3 to -1/2 mile); adjacent (0 ft)
Number of sensors	1,1,0
Sensor types	Pneumatic
Types of treatments	DSFS
Number of relevant sites	4
Number of cases	4
Duration of measurements before activation ("before" measurements)	NS
Time interval between "before" measurements and activation	NS
Duration of activation	1 year
Time of day when speed is measured (a.m./p.m.)	All measurements were taken mid-week for 48 to 72 consecutive hours simultaneously.
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[39]	1 week, 2 months, 7 months, and 1 year

[39] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

37.3. Summary of Study

DSFSs were installed at four experimental sites in Washington and Dakota Counties, Minnesota. There was also one control site. The criteria used to identify the sites were the following.

- Located on county controlled two-lane roads in Washington and Dakota Counties, Minnesota.
- Transition from a rural high speed highway to an urbanized area.
- Reduction in posted speed limit of 10 mph or greater at the transition.
- Existing history of speed related safety concerns.
- No other engineering measures planned at the site for at least 12 months.

The posted speeds were as follows:

- Site 1 (Hugo): 50 to 30 mph
- Site 2 (Bailey): 55 to 40 mph
- Site 3 (Hastings 1): 55 to 45 mph
- Site 4 (Hastings 2): 45 to 35 mph
- Site 5 (Stonebridge, control site): 55 to 30 mph

Vehicle speeds were binned in 1 mph increments at 15-minute intervals. All measurements were taken mid-week for 48 to 72 consecutive hours, simultaneously, at both the upstream and DSFS positions. Measures were taken of mean speed; 50th, 85th, and 95th percentile speeds; and 10 mph pace. These measure were taken 1/3 to 1/2 mile upstream and at the DSFS, which was co-located with the official speed transition. The measures were gathered before and during activation (1 week, 2 months, 7 months, 1 year). Data were not averaged across the sites. Independent variables were as follows: treatment, duration of treatment, time of day, upstream vehicle speed, traffic volume. Dependent variables were as follows: mean speed; 50th (median), 85th, and 95th percentile speeds; 10-mph pace. The major hypothesis was H1B. The publication reported mean speed; 50th, 85th, and 95th percentile speed; 10 mph pace; sample size; standard deviation; and average daily traffic volume

Results. The study reported mean speed results in the tables for each site, but did not report a summary of results across all of the studies. All of the experimental sites showed a statistically and practically significant reduction in mean speed at the DSFS, which persisted throughout the study (one year). The control site did not show a reduction in speed. The results of the study

indicated that DSFS signs at transitions zones have a significant long-term (one year or greater) positive effect on driver speed. This study found overall decreases in speed of approximate six to eight mph at the transition point. The data showed the overall results across all the DSFS sign locations were fairly consistent. The study found:

- Speed reductions of approximately 6-8 mph in the 85th percentile speed (averaging 6.9 mph).
- Average speed reductions of 6.3 and 7.0 mph for the 50th and 95th percentile speeds.
- Decrease of 10 mph in the 10 mph Pace
- Consistent reductions through all time frames including the 24-hour data, a.m. peak hour, and p.m. peak hour.
- Consistent shift across the entire speed distribution to lower speeds.
- At the upstream locations and the control site, the corresponding speeds were either flat or increased slightly over the course of the research.

Statistical Analysis. "Statistical analyses were run on the data comparing changes in vehicle speed distributions as a function of time period and location. Significance testing included an analysis of Variance, Z-test, t-test and Odds Ratio. All statistical measures showed highly significant associations (alpha < 0.01) between the presence of a DSFS and speed reductions within the transition zone."

37.4. Study Schematic

Not provided.

37.5. DSFS Graphic

Not reproduced here. See article.

38. Teng, Xu, Li, Kwigizile, and Gibby, 2009

38.1. Study Characteristics

Item	Response
Authors	Teng, Xu, Li, Kwigizile, and Gibby
Title	Evaluation of Speed Monitoring Displays for Work Zones in Las Vegas, Nevada
Publication year	2009

38.2. Study Features

Feature	Study Information
Experimental design	O-X-O-X-O-X-O-X-O-X-O
Safety focus	Work zone
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	na
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Reduction recorded
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	NA
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	Multiple
Mobile DSFS units	Yes
Roadway type	Multiple
Area type (location)	Rural
Sidewalks present	No
Posted speed	45 mph
Sensor positions	Downstream (200 ft)
Number of sensors	0,0,2
Sensor types	Magnetic
Types of treatments	DSFS (large and small, flashing and non-flashing, 1 device or 2 in series)
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	5 days
Time interval between "before" measurements and activation	6 days
Duration of activation	5 days
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[40]	1 week, 2 months

[40] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	Only graphical data
Best practices information available	Yes

38.3. Summary of Study

This study evaluated how the characteristics of a DSFS system (e.g., message size, presence of flashing, number of DSFS units) may impact effectiveness in terms of vehicle speed reduction. Researchers collected speed data for different treatments and developed regression models to estimate the speeding likelihood and vehicle speeds for various treatment conditions, based on free-flow speed data. Field tests were conducted at two sites in the vicinity of Las Vegas, Nevada. However, only one of the sites (county arterial CR-215) included a "before" condition in which speeds were collected in the absence of any DSFS. The other site is not relevant for this review because it did not include any means of comparing a DSFS condition to a non-DSFS condition. The remainder of this review focuses on details for the one relevant site.

Researchers collected at least 5 days of vehicle speed data for each test condition. Testing of the treatment ("during") conditions began six days after the "before" measurement period. All the various treatment conditions were tested in sequence over 2 months. Data were collected using a magnetometer 200 feet downstream of each DSFS. In one treatment condition there was only one DSFS, but in the other treatment conditions there were two DSFS units, spaced 2,000 feet apart, with a horizontal curve between these two locations, making it impossible for motorists to see the DSFS at the second location when they saw the DSFS at the first location.

Treatment condition	Location 1	Location 2 (2,000 feet downstream)
1 ("before")	No DSFS	No DSFS
2	Small DSFS	No DSFS
3	Big DSFS	Small DSFS
4	Big DSFS with fast flashing	Small DSFS
5	Big DSFS with slow flashing	Small DSFS
6	"Slow Down" message	Small DSFS

Measures were taken of the mean speed, 85th percentile speed, and percent of vehicles exceeding the speed limit. Independent variables were as follows: treatment and location. Dependent

variables were as follows: mean speed, 85th percentile speed, and percent of vehicles exceeding the speed limit. The major hypotheses evaluated were H1B and H2B.

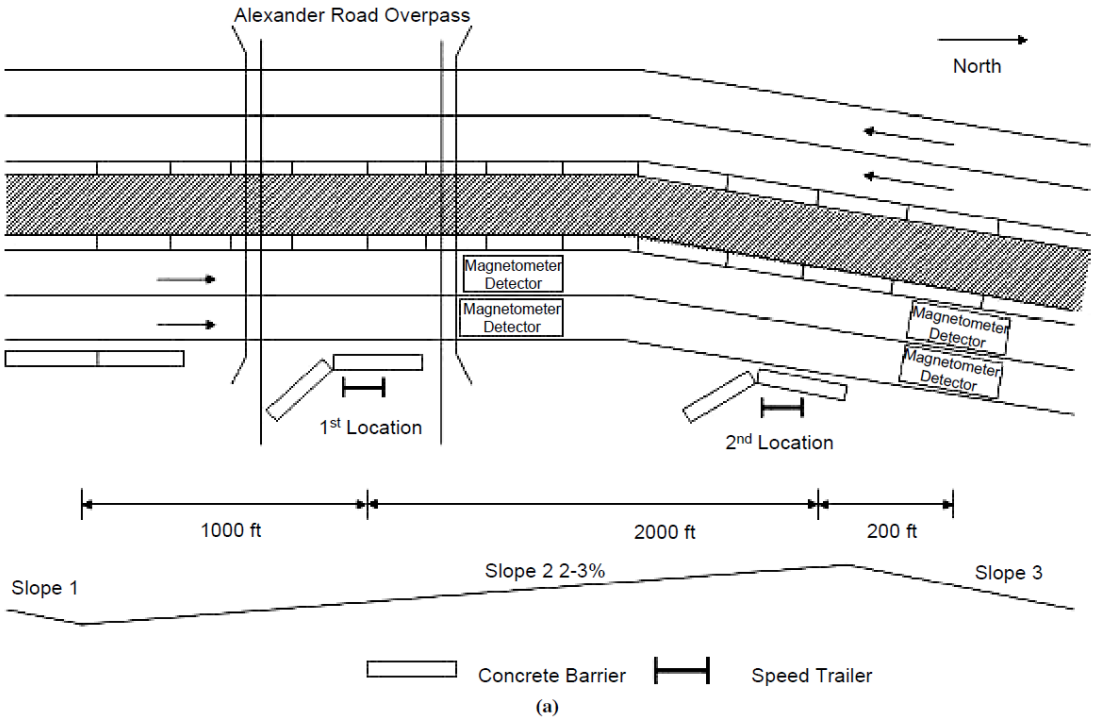
The article reported approximate observed mean speed data for each treatment condition in the form of graphs. It also reported the results of two regression analyses on speeding likelihood (one for the left lane, and the other for the right lane). The goal of the regression modeling was to reveal the relative performance of the treatment scenarios for different vehicles.

Results. The average speeds under the tested scenarios with the presence of a speed trailer ("during condition") were lower than the average speed under the "before condition" for the traffic at the left and right lanes and at both the first and second locations. The scenario with a non-flashing big DSFS had the lowest speeds compared with other scenarios, and the scenario with a non-flashing small DSFS was second, followed by the scenario with a large DSFS with flashing features and a warning message. The presence of a second DSFS sign appeared to result in a further reduction in speeds for vehicles traveling in the right lane.

Statistical Analysis. The authors conducted regression analyses and recorded information on statistical significance for the resulting coefficients. The authors also noted: "The results of the likelihood ratio tests shown in these two tables indicate that these two outcome models were justified statistically. The R-square values of the two linear regression models for speeds are low. Because the purpose of the modeling was to reveal the relative performance of the scenarios for different vehicles, the estimation accuracy as reflected by R-square values became secondary in this study."

38.4. Study Schematic

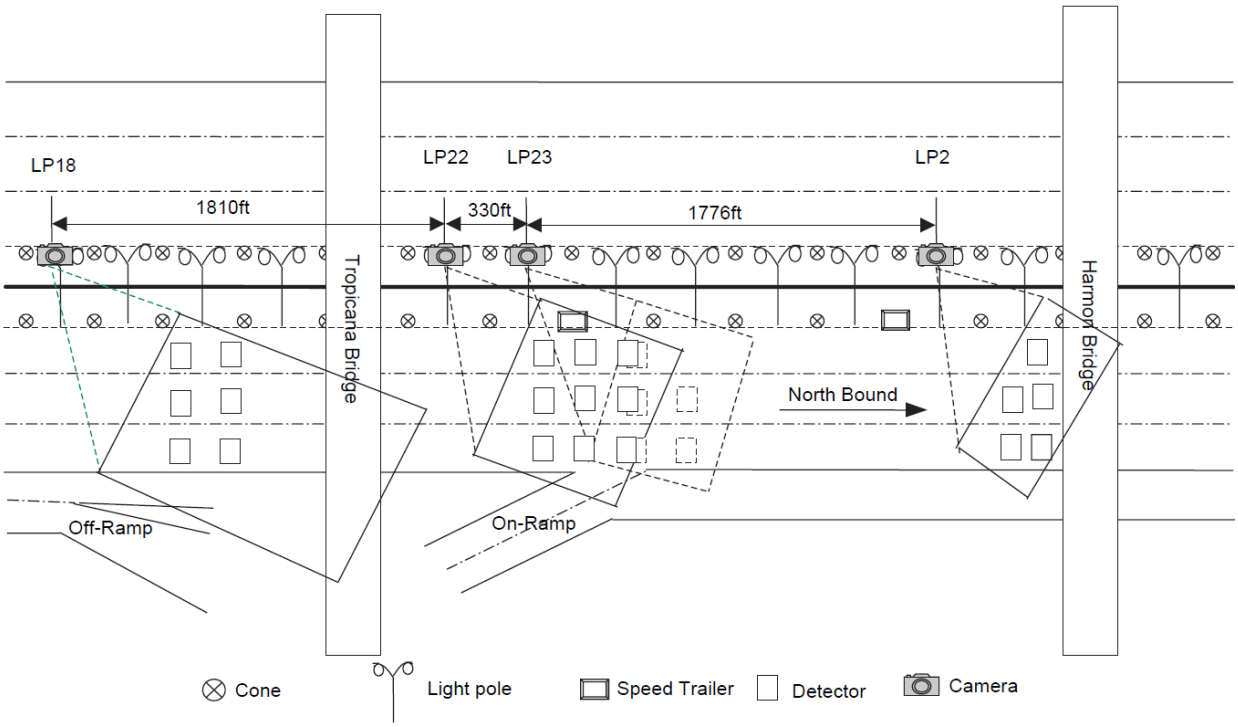
Images courtesy of the authors and reproduced with permission of the Transportation Research Board.



(a)

(b)

Layout of speed trailers and detectors on the test site on CR-216: (a) locations of speed trailers and detectors and (b) big sign speed trailer at first location



Layout of cameras on I-15 test site

38.5. DSFS Graphic

Images courtesy of the authors and reproduced with permission of the Transportation Research Board.

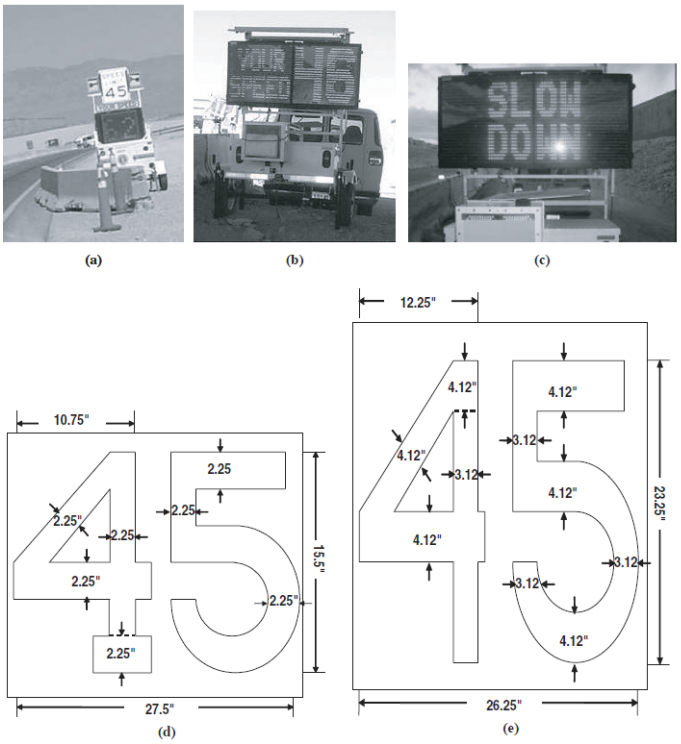


FIGURE 1 Signs and sizes: (*a*) small sign, (*b*) big sign, (*c*) warning sign, (*d*) size of small sign, and (*e*) size of big sign.

Signs and sizes: (a) small sign, (b) big sign, (c) warning sign, (d) size of small sign, and (e) size of big sign

39. Tribbett, McGowen, and Mounce, 2000

39.1. Study Characteristics

Item	Response
Authors	Tribbett, McGowen, and Mounce
Title	An Evaluation of Dynamic Curve Warning Systems in the Sacramento River Canyon
Publication year	2000

39.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	B
Hypothesis 3 (H3) level	na
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction at 3 of 5 sites for trucks and 2 of 5 for cars
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	Yes
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Freeway
Area type (location)	Rural
Sidewalks present	No
Posted speed	55 to 65 mph
Sensor positions	Adjacent (-300 to 0 ft) and downstream (ranging from 100 to 800 ft)
Number of sensors	3
Sensor types	Manual (stopwatch)
Types of treatments	DSFS and changeable message sign
Number of relevant sites	5
Number of cases	10
Duration of measurements before activation ("before" measurements)	3 days
Time interval between "before" measurements and activation	9 months
Duration of activation	10 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[41]	2, 5, and 10 months

[41] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

39.3. Summary of Study

Five dynamic curve warning systems were installed by the California Department of Transportation (Caltrans) to notify motorists of alignment changes and speed advisories in the Sacramento River Canyon, a mountainous area on Interstate 5 between Redding and Dunsmuir. The individual sign systems included a CMS to display both text and diagrammatic curve warnings. The CMS sign systems were also coupled with a radar measurement and display so that both the advisory speed and operating speed of the approaching vehicles would be identified.

Mean speed was the only speed-related measure of effectiveness evaluated in the study. However, the study also investigated non-speed-related measures of effectiveness relevant to safety, including: frequency of crashes, frequency of erratic maneuvers, and reported change in behavior. Finally, the study also evaluated some measures of effectiveness not directly relevant to safety, including: reported public acceptance and reported maintenance requirements.

The speed limit for trucks and autos with trailers was 55 mph for all study sites throughout the analysis period. For passenger cars, the speed limit was 65 mph for the La Moine and Sims Road sites throughout the study period. At the other sites, the speed limit for passenger cars was 55 mph in the "before" condition (the first data collection trip), but was subsequently increased to 65 mph prior to the "during" measurement (the second and all subsequent data collection trips).

To collect this data, four site visits were completed over the course of the evaluation including:

- Before sign deployment (9 months), and
- During (at 2 months, 5 months, and 10 months).

Data were collected during the day. The weather for all of the sites for each of the trips was sunny and clear, with the exception of the Sidehill Viaduct and O'Brien sites, in January 2000, when it was raining and/or the roadway was wet. During each of the four site visits, vehicle speeds were measured at two locations at each site: at the DSFS location (or planned location) and then at the approximate beginning of the curve. Vehicle speeds were measured manually by researchers timing drivers with a stopwatch as they crossed over a 300 foot span. Data collection personnel measured speeds from a vantage point well away from traffic. Due to the low traffic volumes at the designated study sites, researchers considered all vehicles to be operating at a free-flow speed.

The first speed measurement section was measured from 300 feet upstream of the sign to the sign location, and the second section was measured from 300 feet upstream of the curve to the approximate beginning of the curve. The sign at each location was a 10-foot by 7-foot full matrix LED sign supplied by American Signal Company that allows for 50 columns and 28 rows of lights.

The authors noted: "In retrospect, it might have been more appropriate to have positioned the first speed measurement section farther upstream so as to measure the speed at the driver's first sight of the dynamic curve warning system. It is possible that drivers had already seen the dynamic curve warning system and began their deceleration process before reaching the first speed measurement section, in which case both the initial speed measurement and the overall change in speed would have been underestimated."

Additionally, researchers collected, but did not analyze, radar measurements on subsequent unspecified data collection dates. They did report this data in the appendix. Data were collected at three locations.

- Location 1: 1,000 feet upstream of the sign
- Location 2: middle of the first stopwatch speed measurement section (150 feet upstream of the sign)
- Location 3: middle of second stopwatch speed measurement section (150 feet upstream of the beginning of the curve)

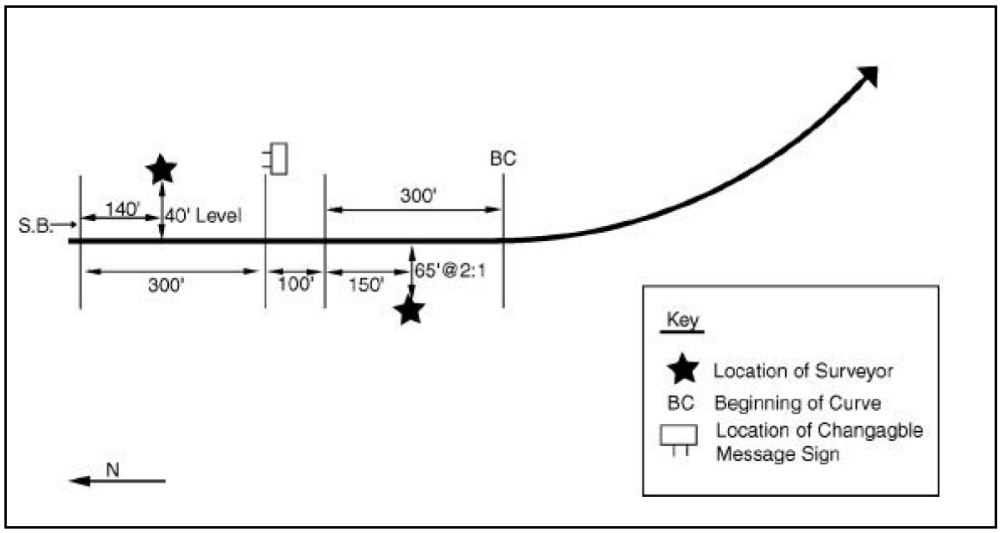
Data were reported separately for trucks and passenger cars, and included mean speeds in addition to other non-speed-related measures of effectiveness.

Results. The authors reported that: "preliminary results indicate reductions in both accidents and operating speeds at selected sites based upon assessment of limited data available and evaluation time period." For trucks, the study observed significant decreases in mean speed for three of five sites, although one of those showed that speeds rebounded in the third and fourth measurement periods. Two of five sites did not show any significant decrease. For passenger cars, the study observed significant decreases in mean speed for two of five sites, while three of five showed no significant change.

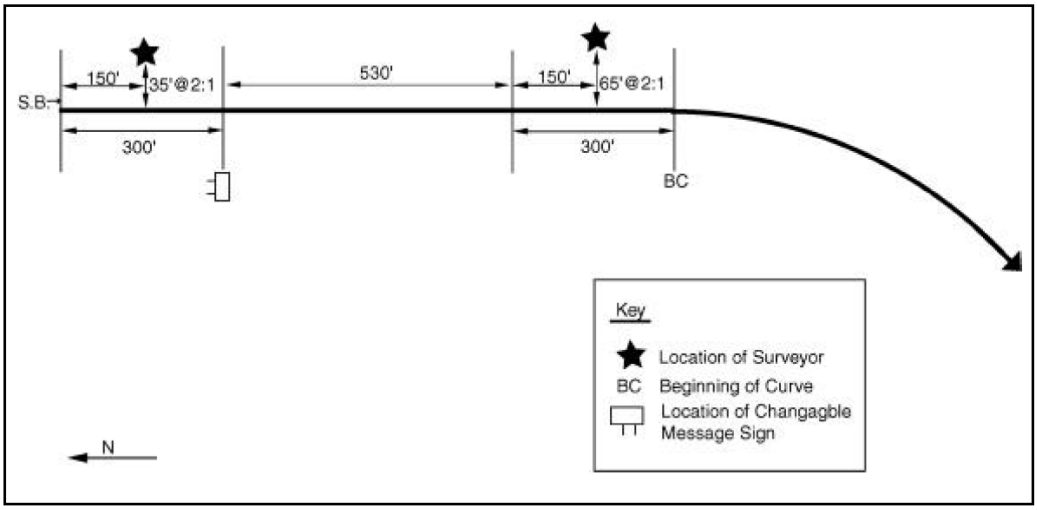
Statistical Analysis. "In order to determine if observed changes in vehicle speeds or erratic maneuvers were statistically significant, standard statistical analysis methods were used, as described by Kleinbaum, Kupper, and Muller (1988), in *Applied Regression Analysis and Other Multivariable Methods*, 2nd edition. For each statistical test, a 95% confidence level (a = 0.05) was used to determine statistical significance. Speed and erratic maneuver data were compared using two sample t-tests and two sample binomial tests."

39.4. Study Schematic

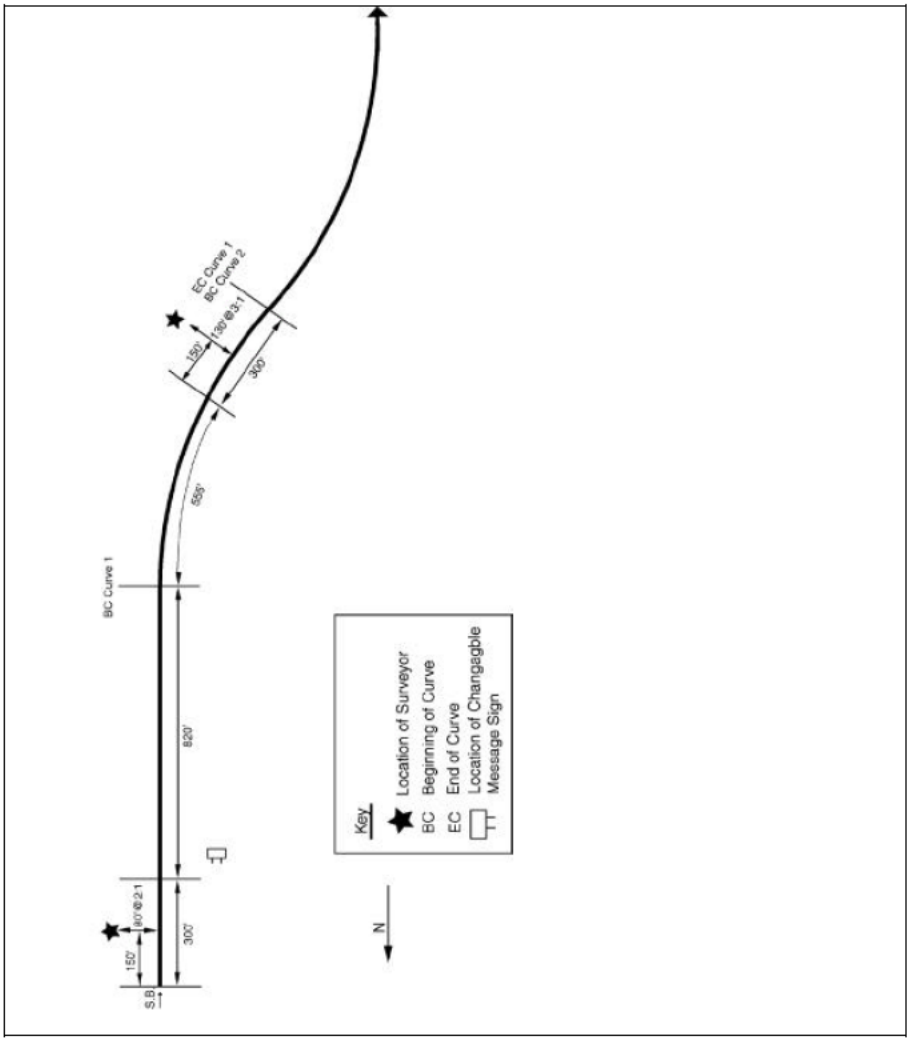
Images courtesy of the authors, the California Department of Transportation District 2, and the Western Transportation Institute.



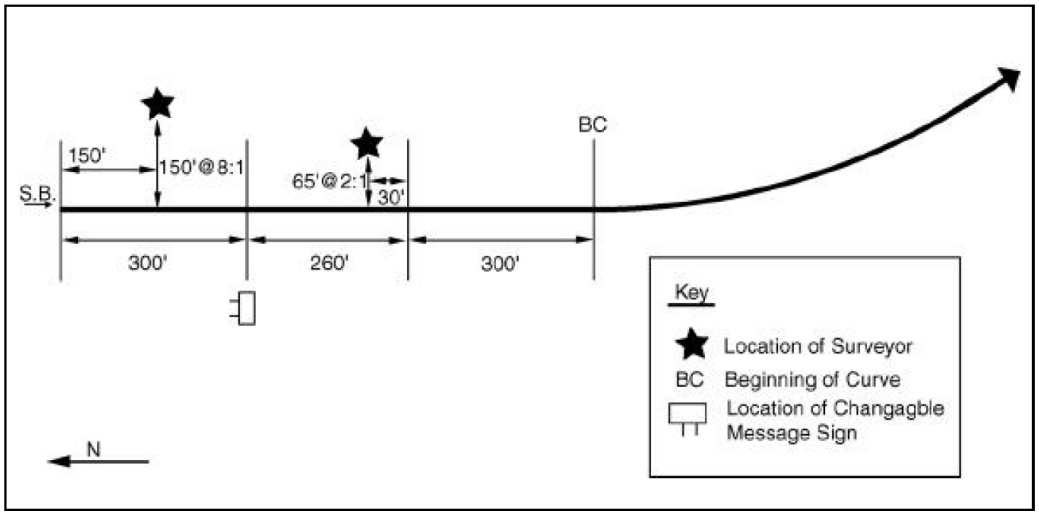
Site Diagram: Sidehill Viaduct



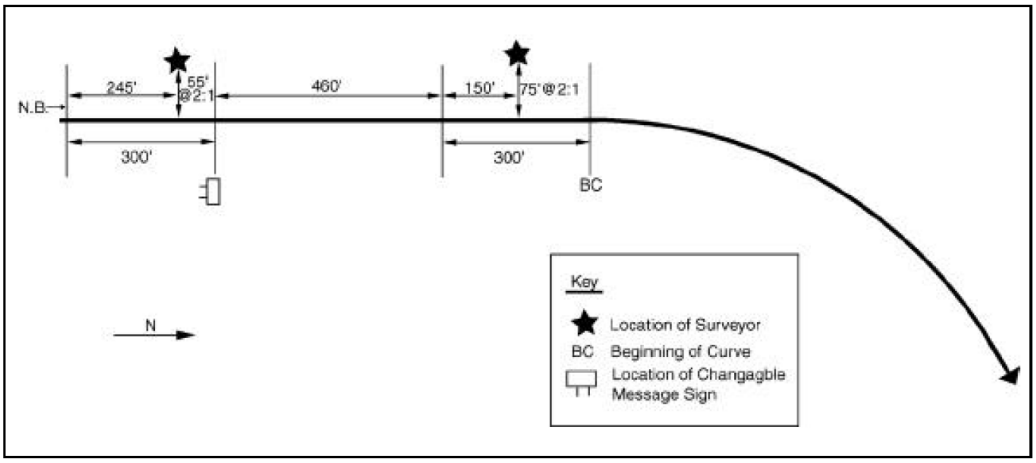
Site Diagram: O'Brien



Site Diagram: Salt Creek

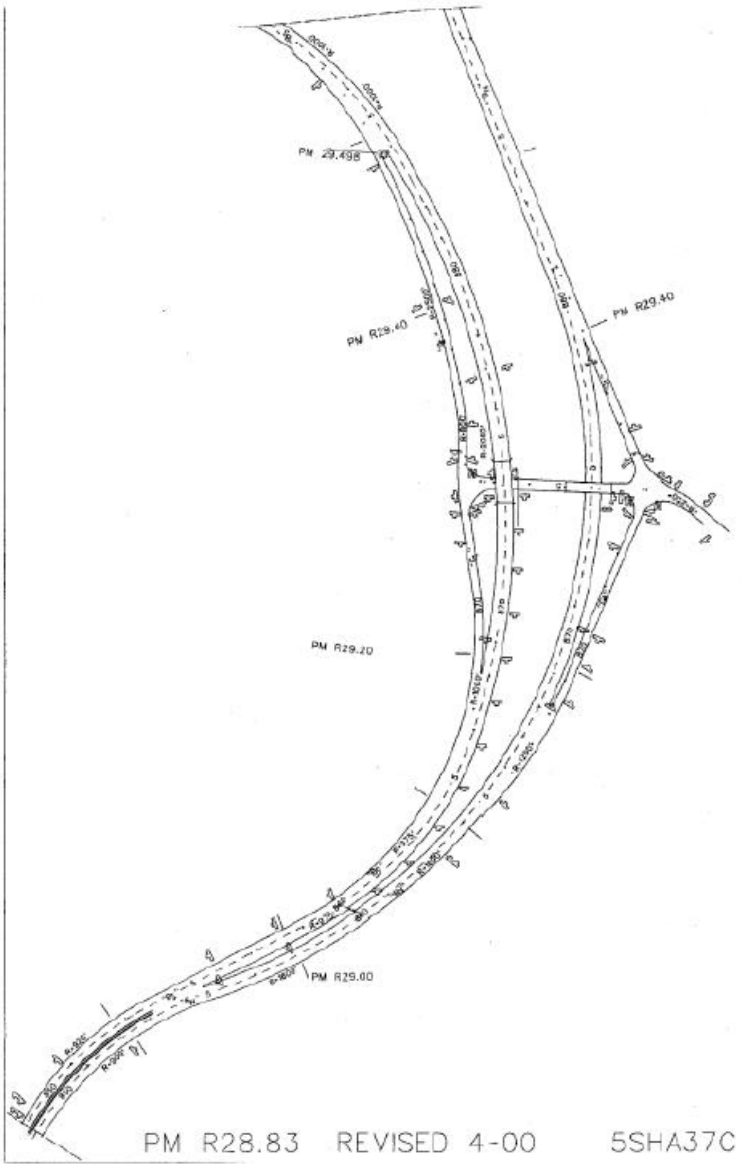


Site Diagram: La Moine



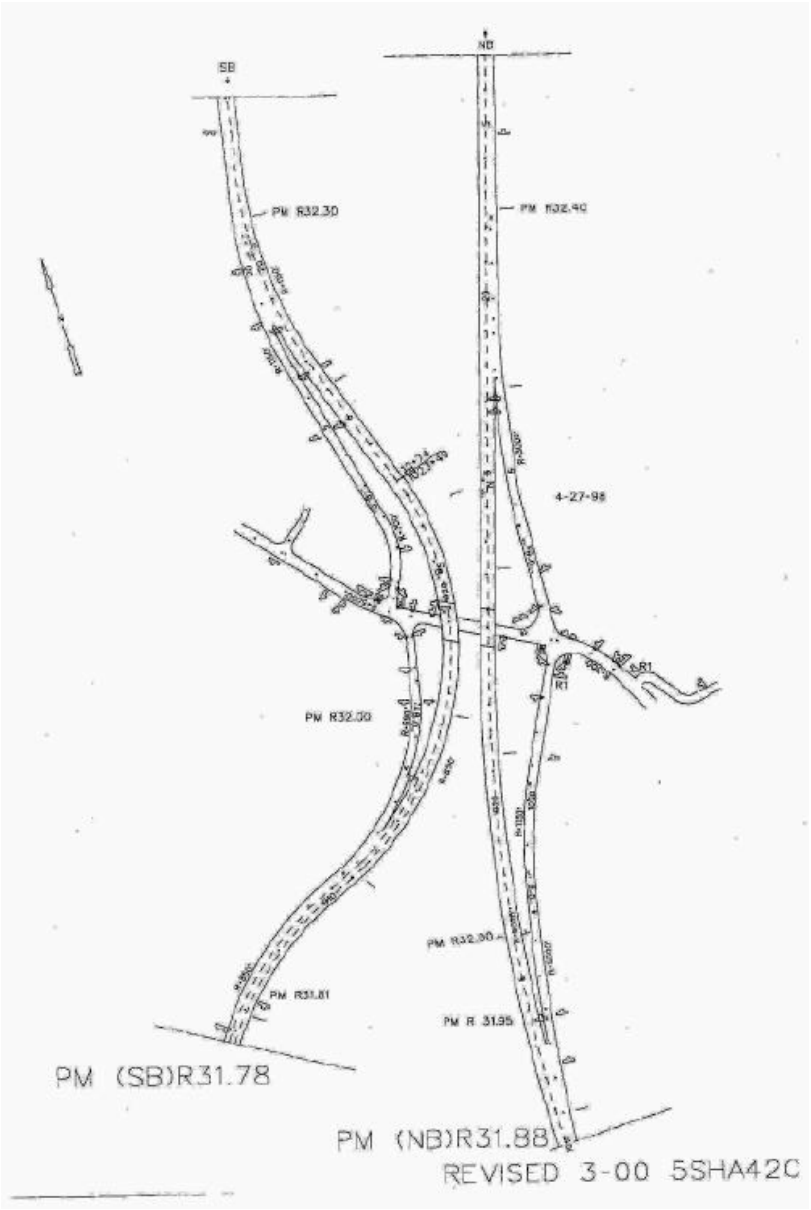
Site Diagram: Sims Road

Site Diagram: Sidehill Viaduct Site Location



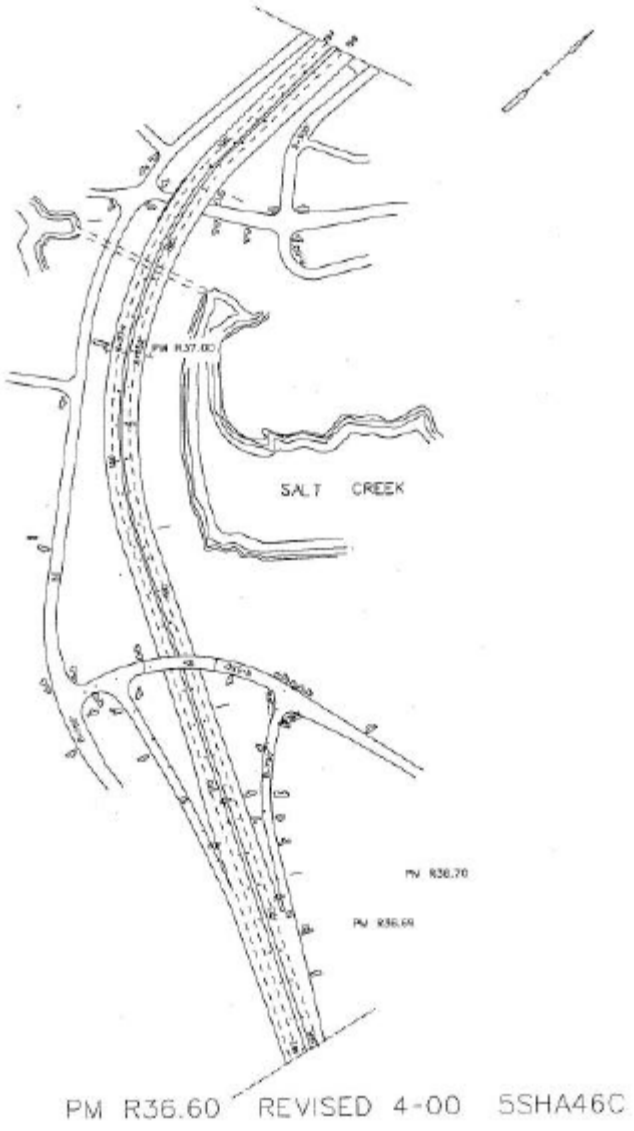
Sidehill Viaduct Curve Layout

O'Brien Site Location



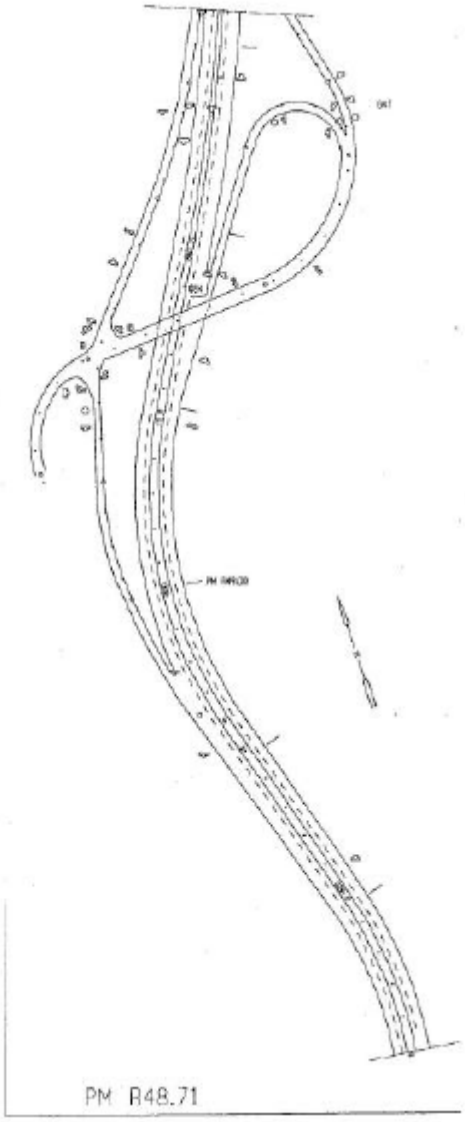
O'Brien Curve Layout

Salt Creek Site Location



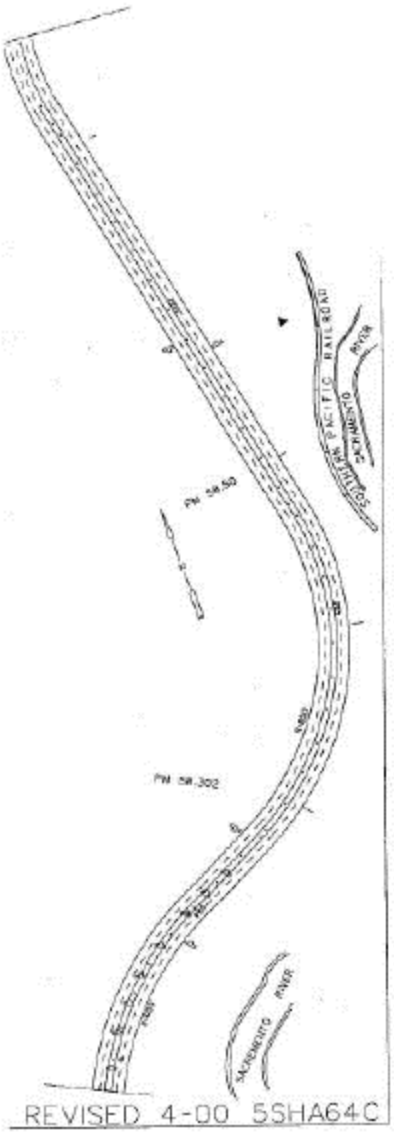
Salt Creek Curve Layout

La Moine Site Location



La Moine Curve Layout

Sims Road Site Location



Sims Road Curve Layout

39.5. DSFS Graphic

Images courtesy of the authors, the California Department of Transportation District 2, and the Western Transportation Institute.

Some Standard Sign Messages

40. Ullman and Rose, 2005

40.1. Study Characteristics

Item	Response
Authors	Ullman and Rose
Title	Evaluation of Dynamic Speed Display Signs
Publication year	2005

40.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Multiple
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	B
Hypothesis 2 (H2) level	NA
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	Reduction recorded
H1: Percentage of drivers over speed limit	Significant reduction recorded
H1: Distribution of speed	Nothing reported
H2: Mean speed	NA
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	Nothing reported
H3: Mean speed	NA
H3: 85th percentile speed	NA

Feature	Study Information
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	LED
DSFS flashes (speed or other)	NS
Mobile DSFS units	No
Roadway type	Multiple
Area type (location)	NS
Sidewalks present	NS
Posted speed	Multiple
Sensor positions	Upstream (-3,000 to -2,000 ft); adjacent (0 ft)
Number of sensors	1,1,0
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	7
Number of cases	9
Duration of measurements before activation ("before" measurements)	2 days
Time interval between "before" measurements and activation	NS
Duration of activation	6-17 weeks
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[42]	Sometime from 1 to 3 weeks and then again sometime 6 to 17 weeks

[42] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

40.3. Summary of Study

DSFSs were installed at seven sites in Texas. The roadway types were as follows.

- Site 1: School zone, one lane in either direction
- Site 2: Advance of school zone, two lanes in either direction
- Site 3: Advance of school zone, two lanes in either direction
- Site 4: Advance of signalized intersection, three lanes in either direction
- Site 5: Advance of signalized intersection, three lanes in either direction
- Site 6: Advance of horizontal curve, two lanes in either direction
- Site 7: Advance of horizontal curve, two lanes in either direction

The posted speeds were as follows.

- Site 1: 55 mph speed limit upstream, 55 mph speed zone at DSFS (35 mph when school zone is active)
- Site 2: 55 mph speed limit upstream, 45 mph speed zone at DSFS
- Site 3: 55 mph speed limit upstream, 45 mph speed zone at DSFS
- Site 4: 70 mph speed limit upstream, 55 mph speed zone at DSFS
- Site 5: 50 mph speed limit upstream, 45 mph speed zone at DSFS
- Site 6: 55 mph speed limit upstream, 30 mph regulatory/20 mph advised at DSFS
- Site 7: 55 mph speed limit upstream, 30 mph regulatory/20 mph advised at DSFS

Measures were taken of the mean speed, the 85th percentile speed, and the percentage of vehicles exceeding the speed limit. These measures were taken 2,000 to 3,000 ft upstream and at the DSFS. The measures were gathered before (2 days), short-term during (2 days of measurement after DSFS had been operating for 1 to 3 weeks), and long-term during (2 days of measurement after DSFS had been operating for 6 to 17 weeks). Data were not averaged across the sites. Independent variables were as follows: treatment, duration of treatment, safety focus/site type, upstream vehicle speed, vehicle type (truck or passenger vehicle). Dependent variables were as follows: average speeds, 85th percentile speeds, and the percentage of the sample exceeding the speed limit. The major hypothesis was H1B. The measures of effectiveness were mean speed, 85th percentile speed, and percentage of vehicles exceeding the speed limit. These measures were reported for each of the seven sites, and for both hypotheses. In each case, the study also reported whether there was a statistically significant difference, at the 0.05

significance level. However, the study did not provide information on sample sizes or variability. The study reported separate results for passenger vehicles and trucks at sites 6 and 7 (the horizontal curve sites), but not for the other sites. At site 1, the article reported separate results for when the school zone was "active" versus "inactive."

Results. Overall, average speeds were reduced by 9 mph at the school speed zone. Elsewhere, the effect of the DSFS was less dramatic, with average speeds reduced by 5 mph or less depending on the location tested. At the two horizontal curve sites (Sites 6 and 7), small decreases in speeds were evident in automobiles approaching those curves (3.5 and 2.1 mph, respectively). Unfortunately, the speeds of large trucks—the target group for the DSFS installation—were essentially unchanged (or even higher in one instance) as compared to speeds in the before conditions. The regression models generated to compare upstream vehicle speed to the speed of the same vehicle at the DSFS location (hypothesizing a positive linear relationship) all had relatively low R^2 values. The authors noted that the slope coefficients dropped slightly between the before and second after studies at several of the test sites. In other words, vehicles approaching at higher speeds appeared to slow down more upon reaching the DSFS location than vehicles approaching at slower speeds.

Statistical Analysis. The statistical significance of effects was determined at the 0.05 significance level. "Statistical comparisons between studies were then performed as appropriate...In addition to the effects of the DSFS on speed reductions, its effect on the dispersion of speeds was also investigated, because several other studies have shown a correlation between higher speed variance and higher crash rates. Overall, the authors found no statistically significant differences in the standard deviation in speeds between any of the three studies at any of the seven test locations...In addition to the spot-speed statistical comparisons, the authors also used regression analysis to compare speeds of individual vehicles tracked through each test site. Specifically, vehicle speed at the upstream control point was compared against the speed of the same vehicle at the DSFS location. A positive linear relationship was hypothesized between the vehicle's speed at the control point and the vehicle's speed at the DSFS installation location. Least-squares regression lines were computed for each study (before, short-term after, and long-term after) and tested for significant differences of regression line coefficients between studies. This procedure allowed researchers to determine whether the effect of the DSFS differed as a function of the approach speed of the vehicle. Researchers hypothesized that the sign could cause those vehicles approaching at higher speeds to slow more substantially than those approaching at slower speeds. The authors tested this hypothesis directly by comparing the slopes of the regression lines for each of the three measurement periods ("before" versus "during (short term)" versus "during (long term)" using an appropriate t-statistic. A smaller slope coefficient in the during study relative to the before condition would indicate a more substantial influence of the DSFS on those vehicles approaching at higher speeds.

40.4. Study Schematic

Not available.

40.5. DSFS Graphic

Image courtesy of the authors and reproduced with permission of the Transportation Research Board.

41. Walter and Broughton, 2011

41.1. Study Characteristics

Item	Response
Authors	Walter and Broughton
Title	Effectiveness of Speed Indicator Devices: An Observational Study in South London
Publication year	2011

41.2. Study Features

Feature	Study Information
Experimental design	O-X-O-O
Safety focus	Straight section
Graphic of DSFS available	No
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	A
Hypothesis 2 (H2) level	A
Hypothesis 3 (H3) level	A
H1: Mean speed	Significant reduction recorded
H1: 85th percentile speed	NA
H1: Percentage of drivers over speed limit	NA
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded at 700 ft downstream, but not at 1,300 ft
H2: 85th percentile speed	NA
H2: Percentage of drivers over speed limit	NA
H2: Distribution of speed	Nothing reported
H3: Mean speed	No change

Feature	Study Information
H3: 85th percentile speed	NA
H3: Percentage of drivers over speed limit	NA
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	NS
Roadway type	Collector
Area type (location)	Urban
Sidewalks present	NS
Posted speed	30 mph
Sensor positions	Upstream (-700 ft); adjacent (0 ft); downstream (700 ft, 1,300 ft)
Number of sensors	1,1,2
Sensor types	Inductive loops
Types of treatments	DSFS
Number of relevant sites	10
Number of cases	10
Duration of measurements before activation ("before" measurements)	1 week
Time interval between "before" measurements and activation	0 days
Duration of activation	1-3 weeks
Time of day when speed is measured (a.m./p.m.)	NS
Time of day when speed is measured (peak/off peak)	NS
Time intervals at which measurements were taken during activation ("during" measurements)[43]	1,2, and 3 weeks

[43] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	0 days
Duration of "after" measurements	1 and 2 weeks
Meta-analysis data available	Yes
Caveats	International, thus not included
Best practices information available	No

41.3. Summary of Study

Dynamic speed feedback signs were installed at 10 sites in South London, United Kingdom. The sites were straight sections of roadway of about 1 km in length where traffic was freely flowing (Level A). All sites had a posted speed of 30 mph. Measures were taken of the mean speed, the maximum speed, and the minimum speed 200 m upstream of the DSFS, at the DSFS, and 200 m (10 sites) and 400 m (6 sites) downstream of the DSFS. Treatment condition was the independent variable (before – 1 week, during – 1, 2, 3 weeks, after – 1, 2 weeks). Three major hypotheses were evaluated: H1A, H2A, and H3A.

Data Reported. The data reported include the following: (a) Activation effect adjacent to the DSFS on mean, max and min speed; (b) Activation effect downstream (200 m, 400 m) for mean, max and min speed; and (c) Deactivation effect adjacent to the DSFS 1 week and 2 weeks after removal on mean speed, max speed, and min speed.

Results. The results are as follows for changes in mean speeds. H1A: There was a statistically significant decrease in the mean speed of -1.4 mph at the DSFS when it was activated compared to baseline. H2A: There was a statistically significant decrease of -0.2 mph 200 m downstream of the DSFS when it was activated compared to baseline; there was no significant change in the mean speeds 400 m downstream of the DSFS. H3A: When compared with baseline, there was no significant change in the mean speeds at the DSFS 1 week after the DSFS was turned off but there was a statistically significant increase of 0.1 mph at the DSFS 2 weeks after the DSFS was turned off. **Other Results**. Similar results held for measures of the maximum and minimum speeds. For example, there was an overall reduction of 2.6 mph in the maximum speed and an overall reduction of 0.6 mph in the minimum speed when the DSFS was activated.

Statistical Analysis. ANOVA contrasts (or planned comparisons) were done on the dependent variables:

$$\delta_x(t) = \left(\mu_x(t) - \mu_x(\text{before})\right) - \left(\mu_1(t) - \mu_1(\text{before})\right)$$

Where x is defined from 1 (-200 m before SID), 2 (at SID), 3 (200 m post SID), 4 (400 m post SID)

41.4. Study Schematic

Not provided.

41.5. DSFS Graphic

Not provided.

42. Western Transportation Institute, 2003

42.1. Study Characteristics

Item	Response
Authors	Western Transportation Institute
Title	Greater Yellowstone Rural ITS Project: Work Order II-2C Dynamic Warning VMS Evaluation of Wyoming Site
Publication year	2003

42.2. Study Features

Feature	Study Information
Experimental design	O-X-O
Safety focus	Horizontal curve
Graphic of DSFS available	Yes
Graphic of layout available	Yes
Study restricted to free flow level of service	NS
Classes of vehicles included	Passenger cars and trucks
Hypothesis 1 (H1) level	A,B
Hypothesis 2 (H2) level	A,B
Hypothesis 3 (H3) level	NA
H1: Mean speed	Significant decrease only at location 5
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction only at location 5
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Nothing reported
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported

Feature	Study Information
H3: 85th percentile speed	Nothing reported
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	No
DSFS speed lighting	Yes
DSFS flashes (speed or other)	No
Mobile DSFS units	No
Roadway type	Local
Area type (location)	Rural
Sidewalks present	No
Posted speed	NS
Sensor positions	Upstream (-2,112 ft, -1,478 ft), adjacent (just downstream) and downstream (2,112 ft, 2,904 ft, and 8,184 ft)
Number of sensors	2,1,3
Sensor types	Multiple (magnetic and pneumatic)
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	2
Duration of measurements before activation (“before” measurements)	2 weeks
Time interval between “before” measurements and activation	2 weeks
Duration of activation	2 weeks
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple

Feature	Study Information
Time intervals at which measurements were taken during activation ("during" measurements)[44]	2 weeks
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	Yes
Caveats	None
Best practices information available	No

42.3. Summary of Study

This study evaluated the effectiveness of a DSFS installed on winding, rural Wyoming highway 14A, with significant grades. This was just one component of the Greater Yellowstone Rural Intelligent Transportation System Project, which also encompassed two other evaluations in Idaho and Montana. In addition to analyzing speeds as a measure of effectiveness, the study also included a motorist survey and an analysis of crash data.

Inductive loops 0.3 miles upstream were used to detect the size and speed of vehicles approaching the DSFS. The regulatory speed limit was not specified, but the DSFS displayed advisory messages to vehicles that exceeded a speed threshold for their size category. The speed thresholds were as follows.

- Vehicles less than 22 feet: 40 mph
- Vehicles greater than 22 feet: 35 mph

The advisory warning included two panels: "Curves Ahead" and "Slow Down." The DSFS was approximately 10 feet wide, 4 feet tall, and 2 feet deep, and showed LED characters with a text height of 12 inches.

Vehicle spot speeds and classifications were collected for a 2-week period prior to the DSFS installation (using magnetic sensors) and a 2-week period after (using pneumatic sensors). Researchers programmed the data collection equipment to record the average speed for each 2-hour interval, rather than recording individual vehicle speeds. Data were collected at two upstream, one adjacent, and three downstream locations. The study evaluated hypotheses H1A, H1B, H2A, and H2B.

Unfortunately some of the magnetic sensors were dislodged by passing vehicles, ruining some of the "before" data collection. This was the reason the researchers switched to pneumatic tubes for the "during" data collection. Unfortunately, these two technologies classify vehicles in slightly

[44] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

different ways; e.g., a passenger car towing a trailer would have been classified as a truck in the "before" data collection, but would have been classified as a passenger car in the "during" data collection. This likely introduced some error in the "before" and "during" comparisons for specific vehicle types. Also, researchers noted that the two sensor types may have different errors. They conducted tests and determined that the magnetic sensors tend to overestimate speed by an average of 1.5 mph when compared to the pneumatic tubes. To compensate, they subtracted 1.5 mph from the "before" speeds. Researchers also noted that the "during" sensors may have collected data at slightly different locations than the "before" sensors, but difference between the pre- and post- locations was estimated to be 0.1 miles or less.

The publication reported mean speeds and adjusted mean speeds (to compensate for different sensor types), as well as sample sizes and standard deviations for passenger vehicles and trucks.

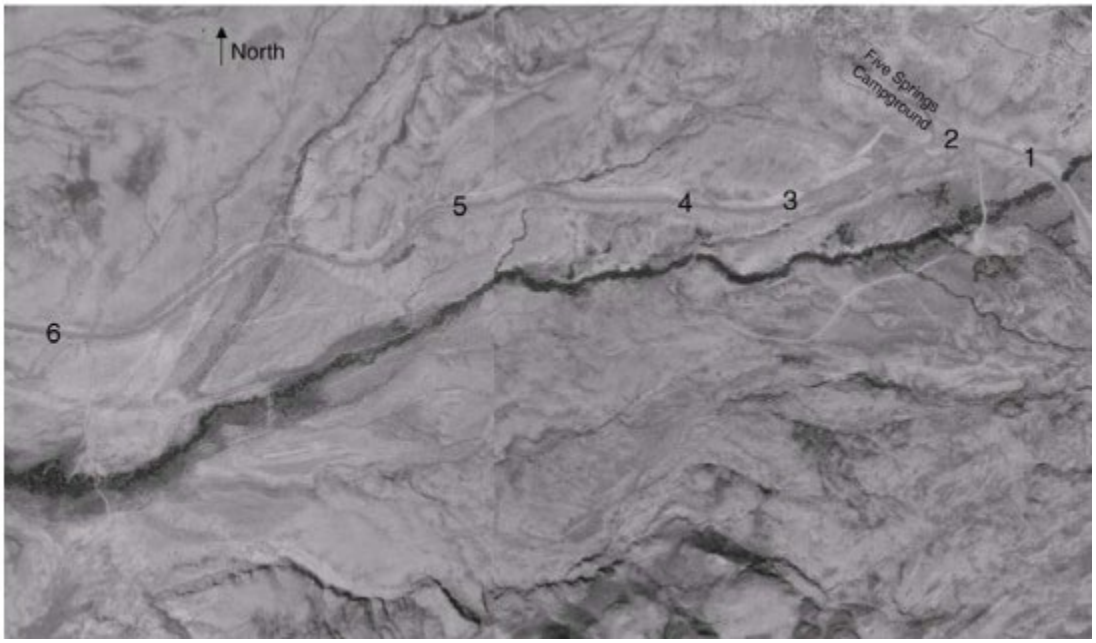
Results. When compared to speed after the installation was complete, there was a statistically significant reduction in vehicle speeds at the sharp curves for both passenger cars and trucks.

Statistical Analysis. The researchers determined whether observed differences were statistically significant at the 0.05 level of significance, in most cases using a one-tailed t-test.

42.4. Study Schematic

Images courtesy of Patrick McGowen of the Western Transportation Institute.

GYRITS Study Area



Locations of Speed Data Collection

Static Sign (left) and Sharp Curves (right)

42.5. DSFS Graphic

Images courtesy of Patrick McGowen of the Western Transportation Institute.

43. Williamson and Fries, 2015

43.1. Study Characteristics

Item	Response
Authors	Williamson and Fries
Title	Effectiveness of Radar Speed Signs in a University Environment
Publication year	2015

43.2. Study Features

Feature	Study Information
Experimental design	X-O
Safety focus	Transition zone
Graphic of DSFS available	Yes
Graphic of layout available	No
Study restricted to free flow level of service	Yes
Classes of vehicles included	NS
Hypothesis 1 (H1) level	NA
Hypothesis 2 (H2) level	C
Hypothesis 3 (H3) level	NA
H1: Mean speed	Nothing reported
H1: 85th percentile speed	Nothing reported
H1: Percentage of drivers over speed limit	Nothing reported
H1: Distribution of speed	Nothing reported
H2: Mean speed	Significant reduction recorded
H2: 85th percentile speed	Nothing reported
H2: Percentage of drivers over speed limit	Significant reduction recorded
H2: Distribution of speed	Nothing reported
H3: Mean speed	Nothing reported
H3: 85th percentile speed	Nothing reported

Feature	Study Information
H3: Percentage of drivers over speed limit	Nothing reported
H3: Distribution of speed	Nothing reported
DSFS displays speed	Yes
DSFS speed lighting	NS
DSFS flashes (speed or other)	NS
Mobile DSFS units	Yes
Roadway type	Local
Area type (location)	Suburban
Sidewalks present	NS
Posted speed	25 mph
Sensor positions	Adjacent (NS) and downstream (620 ft)
Number of sensors	0,1,1
Sensor types	Lidar
Types of treatments	DSFS
Number of relevant sites	1
Number of cases	1
Duration of measurements before activation ("before" measurements)	NA
Time interval between "before" measurements and activation	NA
Duration of activation	9 months
Time of day when speed is measured (a.m./p.m.)	Multiple
Time of day when speed is measured (peak/off peak)	Multiple
Time intervals at which measurements were taken during activation ("during" measurements)[45]	9 months

[45] The duration of "during" measurement periods was not collected, because this information was often not explicitly stated.

Feature	Study Information
Amount of time that elapsed after deactivation and prior to subsequent measurements ("after" measurements)	NA
Duration of "after" measurements	NA
Meta-analysis data available	No
Caveats	NA
Best practices information available	No

43.3. Summary of Study

This study investigated the effect of a DSFS placed for an extended period of time on a road segment entering a university campus. The site was frequented by pedestrians and law enforcement and was known to have an existing speeding problem.

The sign was movable but had been installed for 9 months before the "during" data were collected. Researchers collected speed data in optimal weather conditions during weekday peak periods and on Saturday during an off-peak time. The speed limit upstream was 45 mph, transitioning to a 25 mph speed limit in the study area. The DSFS was placed in the 25 mph zone, but upstream of the area frequented by pedestrians.

Researchers used a handheld radar gun to record vehicle speeds near the point where pedestrians cross the roadway (620 feet downstream of the DSFS). The location was on the south end of campus, more than 2 miles from the nearest signalized intersection. Many drivers would have just finished a commute at interstate speeds before entering campus. Lead vehicles were identified and tracked through the study area; no following vehicles were used to ensure that each driver was independently setting their speed under free-flow conditions. The measures of effectiveness were mean speed and the percent of vehicles exceeding the speed limit. The hypothesis investigated was H2C.

Data reported. Mean speed reductions and percent of speeders responding to the DSFS.

Results. The upstream and downstream speeds "during" measurements of each vehicle were compared using a statistical approach to identify the overall effectiveness of the radar speed signs. The findings suggest with 99 percent significance that drivers traveling above the speed limit reduced their speed by a mean of 1.19 mph, while drivers traveling below the posted speed limit increased their speed by a mean of 2.33 mph. Also, 85.6 percent of drivers reduced their speed when warned that they were speeding.

Statistical Analysis. "The two speed measurements of each vehicle were compared using a statistical approach to identify the overall effectiveness of the radar speed signs. Two additional groups were tested: those vehicles traveling above and below the posted speed limit at point 1."

43.4. Study Schematic

Not provided

43.5. DSFS Graphic

Image courtesy of the authors.

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