Radar Speed Sign Effectiveness Study

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RK&K

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I. Introduction

Radar speed signs (RSS's) display a vehicle's travel speed to provide the motorist with feedback on their current speed. Typically, RSS's measure travel speeds using a radar unit contained within the sign assembly. DelDOT currently uses two types of RSS's: standalone units, which only provide motorists with their current speed, while others are posted with a static speed limit sign. DelDOT receives numerous requests for RSS's from citizens and legislators. DelDOT's Radar Speed Sign Policy - Update 2015 notes that RSS's are often popular with the public and allows them to be installed on roadways if they are funded through the Community Transportation Fund (CTF) process or other non-DelDOT sources. However, the policy also notes that the effectiveness of RSS's is questionable at best, and the majority of studies conducted across the country have shown negligible speed reductions. DelDOT requested that RK&K perform the current research effort to study multiple sites in Delaware where RSS's have been installed on roads with different functional classifications, volumes, and posted speed limits to determine if the signs have been effective at reducing speeds. This report presents the methodology, conclusions, and recommendations of the study. Examples of RSS's are shown below in **Figure 1**.

Figure 1: Examples of radar speed signs in Delaware

II. Literature Review

Previous studies on RSS's have found varying levels of speed reductions (and in some cases, little or no long-term reductions in speed) depending on the location of the sign. Overall, the literature review found RSS's installed at generic locations typically result in lower speed reductions than signs installed at locations where drivers understand the need to slow down.

A 2020 meta-analysis of the long-term effectiveness of RSS's found that previous installations resulted in small impacts on speed, including initial reductions of 1 to 3 mph before returning to normal after 4 weeks[1]. The same study evaluated RSS's installed on 6 roadways with different speed limits and functional classifications and found that, 5 years after installation, there were statistically significant speed *increases* of approximately 1 mph. The FHWA's Desktop Reference of Potential Effectiveness in Reducing Speed, which lists observed speed reductions associated with common speed management countermeasures, shows RSS's reduce mean speeds by about 1 mph and 85th percentile speeds from 2 to 6 mph on 2-lane roads and collectors or minor arterials[2]. Preliminary results from a separate meta-analysis of 43 publications that studied RSS installations found that 92 percent of the studies reported a significant speed reduction at the RSS and 63 percent of the studies reported a speed reduction downstream of the RSS, with an average speed reduction of 4 mph[3], although this study did not note where signs were installed. Another study conducted by the ITE Speed Reduction Techniques Technical Committee evaluated 116 sites where RSS's

were installed and found average speeds reduced by 1.8 mph on local streets, 2.6 mph on collector streets, and 3.9 mph on arterials; however, it is noted that this study did not note where signs were installed, and due to the nationwide scope, likely included sites such as school zones or work zones[4]. A study conducted by the National Institute for Transportation and Communities (NITC) that evaluated RSS effectiveness included a summary of previous RSS studies, which found that average speed reductions in generic areas (e.g., those not near a school, curve, etc.) ranged from 1.4 to 6 mph, and the study itself found that disabling RSS's created statistically significant speed increases of 0.5 to 2.1 mph[5].

Multiple past studies have also evaluated the effectiveness of RSS installation at specific locations where it would be prudent for drivers to reduce speeds. The 2020 meta-analysis of the long-term effectiveness of RSS's discussed above found speed reductions of 3 to 9 mph in school zones measured 4 years after installation in one study, reductions of 1 to 7 mph in school zones 12 months after installation in another study, and reductions of 1 to 8 mph in speed transition zones 12 months after installation[1]. The authors found RSS's were most effective on local streets with one-lane approaches or on roadways with schools. The NITC study[5] found that RSS's reduced average speeds by 6 to 11 mph in school zones, horizontal curves, and speed transition areas compared to 1.4 to 6 mph in unspecified areas. The FHWA's Desktop Reference of Potential Effectiveness in Reducing Speed shows RSS's reduce mean speeds between 0 to 7 mph and 85th percentile speeds between 1 to 6 mph at school zones, curves, work zones, community entrances, and intersections[2]. One study that evaluated RSS effectiveness at 4 speed reduction transition zones (where rural highways transition into low-speed urbanized areas) found the signs provided statistically significant and practically significant speed reductions over one year, including 6 to 8 mph reductions in the 85th percentile speed and a consistent shift in speed distribution to lower speeds[6]. A Texas Transportation Institute study examined the impacts of RSS's at school zones, upstream of school zones, at sharp horizontal curves, and approaching intersections[7] and found 9 mph average speed reductions 4 months after installation at school zones, 1 to 2 mph average speed reductions upstream of school zones, no changes in vehicle speeds at sharp horizontal curves, and 0 to 4 mph average speed reductions approaching signalized intersections.

RSS manufacturers have also cited past research touting the effectiveness of the devices or have conducted their own research. A blog post from manufacturer TraffiCalm cited a study where RSS's were installed on a collector road with schools and a park and found a statistically significant decrease in speeds of 1 to 2 mph[8]. Despite the low speed decrease, community groups were pleased and the police department saw a decline in traffic complaints from concerned citizens. A study conducted by the 3M Traffic Safety Systems Division cited two work zone studies that found mean speeds were reduced by 3 to 4 mph after RSS installation[9]. 3M also conducted 3 field tests and found the 85th percentile speeds were reduced by approximately 6 mph and the mean speeds were reduced by approximately 5 mph after RSS installation.

Taken collectively, previous studies have found RSS installation may result in statistically significant average speed reductions, even though the magnitudes of such reductions are typically relatively small, on the order of 0.5 to 6 mph. However, several studies have shown the speed reductions are larger and more sustained (up to 11 mph) when RSS's are installed at locations where drivers understand the need to slow down, such as in school zones or work zones. It should also be noted that prior studies have found that the simple presence of an RSS can satisfy concerned citizens, even when speed reductions after RSS installation may not be noticeable to the average driver.

III. Methodology

To study the effectiveness of RSS's in Delaware, multiple sites throughout the state were identified to study speeds before and after RSS's were installed. These sites were chosen based on requests received from citizens and legislators over multiple years. In addition to a before-after comparison of vehicle speeds, a statistical analysis was completed to determine if speed changes were statistically significant. This section discusses the sites analyzed, as well as the before-after comparisons and statistical analyses conducted.

Data Collection Sites

This study is based on travel speed data that were collected before and after installation of RSS's at 23 sites in Delaware. These 23 sites included 9 sites that had been studied prior to the commencement of this study; 7 of those sites are on SR 7, SR 41, and SR 48 all of which are arterial roadways, and the other 2 sites are on Yale Road which also incorporated the study of multiple additional speed reduction treatments after installation of RSS's. The remaining 14 sites included in this study were new installations that were all studied in a consistent manner for the purposes of evaluating their effectiveness at reducing speeds.

At the 14 new sites, speeds were collected both at the sign and downstream of the sign to determine if motorists reduced their speeds at/near the sign, and also if they maintained the reduced travel speeds beyond the sign. Speeds were also collected upstream of each sign to account for any changes to the prevailing speeds that were not attributable to the signs, however those data are not included in this report for brevity. At the 7 sites on SR 7, SR 41, and SR 48, speeds were collected only at the sign and downstream of the sign. At the two 2 Yale Road sites, speeds were collected only at the sign. The data collection sites and dates of sign installation and data collection are shown below in **Table 1**. The sites were chosen to include roadways with a variety of posted speed limits, functional classifications, and geographically spread across all three Delaware counties.

Table 1: Data Collection Sites

Category	Site #	Site Description	Speed Limit (mph)	Before Data Collection	Sign Installation	After Data Collection
Residential subdivision sites	1	NB Yale Road, Wilmington, DE	25	10/1/20 – 10/6/20	Fall 2020	1/14/21 – 1/20/21
	2	SB Yale Road, Wilmington, DE	25	10/1/20 – 10/6/20	Fall 2020	1/14/21 – 1/20/21
	3	2714 EB Bardell Dr, Wilmington, DE	25	1/12/21 – 1/20/21	6/29/21	8/20/21 – 8/26/21
	4	NB Glenoak Rd (300' N of Faulkland Road), Wilmington, DE	25	11/9/21 – 11/17/21	1/18/22	3/4/22 – 3/10/22
	5	SB Glenoak Rd (950' N of Faukland Road), Wilmington, DE	25	11/9/21 – 11/17/21	1/18/22	3/4/22 – 3/10/22
	6	EB Wildwood Dr, Wilmington, DE	25	11/12/21 – 11/18/21	1/1822	3/16/22 – 3/22/22
Municipal/town streets	7[1]	254-222 W State St (EB), Millsboro, DE	25	6/4/19 – 6/10/19	June 2019	8/6/19 – 8/14/19
	8	EB Jefferson Bridge Rd (75' W of Ocean Pines Ln)	35	8/25/20 – 9/1/20	Fall 2020	7/19/21 – 7/28/21
	9[2]	SB Rd 240 (Main St), Viola, DE	25	8/27/20 – 9/3/20	Fall 2020	12/7/20 – 12/15/20
Arterials – Kent and/or Sussex Counties	10	29800 Millsboro Hwy (EB), Millsboro, DE	45	6/4/19 – 6/10/19	June 2019	8/6/19 – 8/14/19
	11	SB Parker House Rd (1,200' S of Beaver Dam Rd)	40	8/25/20 – 9/1/20	Fall 2020	7/19/21 – 7/28/21
	12	NB Parker House Rd (1,200' S of Beaver Dam Rd)	40	8/25/20 – 9/1/20	Fall 2020	7/19/21 – 7/28/21
	13	EB Gills Neck Rd (100' E of Red Tail Rd)	35	12/7/21 – 12/13/21	12/23/21	3/3/22 – 3/9/22
	14	WB Gills Neck Rd (150' W of Spinnaker Dr)	35	12/7/21 – 12/13/21	12/23/21	3/3/22 – 3/9/22
Arterials – New Castle County (Sites 15-21 previously collected as part of SR 7/41/48 RSA)	15	SB SR 7 between Milltown Rd and Pickwick Dr	40	7/26/18 – 7/30/18	August 2018	3/28/19 – 4/4/19
	16	SB SR 7 between Stenning Dr and Valley Rd	50	7/19/18 – 7/23/18	August 2018	3/26/19 – 4/2/19
	17	SB SR 41 between Valley Rd and Yorklyn Rd	35	7/26/18 – 7/30/18	August 2018	4/2/19 – 4/9/19
	18[3]	NB SR 41 between Graves Rd and Loveville Rd/McKennans Church Rd	45	7/19/18 – 7/23/18	August 2018	3/26/19 – 4/2/19
	19	SB SR 41 between Faulkland Rd and Milltown Rd	35	No data collected[4]	August 2018	3/28/19 – 4/4/19
	20	NB SR 48 between Centre Rd and Harlech Dr	45	7/19/18 – 7/23/18	August 2018	3/26/19 – 4/2/19
	21	SB SR 48 between Old Wilmington Rd & Hercules Rd	50	7/19/18 – 7/23/18	August 2018	3/26/19 – 4/2/19
	22	NB School Bell Rd (80' S of Jamestown Dr)	40	6/5/19 – 6/10/19	6/20/2019	7/30/19 – 8/7/19
	23	SB School Bell Rd (280' N of Dasher Ave)	40	6/5/19 – 6/10/19	6/20/2019	7/30/19 – 8/7/19

The below 3 sites were near a feature the literature review identified as one with higher effectiveness of RSS's:

1. *Site 7 is located 100 feet upstream of park*
2. *Site 9 is located 450 feet downstream of first SPEED LIMIT 25 sign in speed transition zone from 50 mph to 25 mph*
3. *Site 18 is located 450 feet upstream of Cooke Elementary School driveway and 215 feet upstream of School warning sign and pavement marking*
4. *"Before" data was not collected at Site 19 due to construction.*

Speed data were collected using pneumatic road tubes. Raw vehicle speeds were grouped into bins depending on the posted speed limit. The bins are shown below in **Table 2**.

Table 2. Speed Bins (mph)

Speed Limit	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10	Bin 11	Bin 12
25	0-9	10-14	15-19	20-22	23-25	26-28	29-31	32-34	35-39	40-44	45-49	> 50
30	0-14	15-19	20-24	25-27	28-30	31-33	34-36	37-39	40-44	45-49	50-54	> 55
35	0-19	20-24	25-29	30-32	33-35	36-38	39-41	42-44	45-49	50-54	55-59	> 60
40	0-24	25-29	30-34	35-37	38-40	41-43	44-46	47-49	50-54	55-59	60-64	> 65
45	0-29	30-34	35-39	40-42	43-45	46-48	49-51	52-54	55-59	60-64	65-69	> 70
50	0-34	35-39	40-44	45-47	48-50	51-53	54-56	57-59	60-64	65-69	70-74	> 75

It should be noted that for analysis of binned data, it was assumed that vehicle speeds are uniformly distributed within each bin. Bin 1 and Bin 12 counts were not used for numerical analysis because the uniform distribution is an unrealistic assumption for the lower bound (Bin 1) and there is no upper limit for Bin 12.

Before-After Comparisons and Statistical Analysis

To analyze the effectiveness of RSS's on vehicle speeds, the effects of other factors that could potentially impact vehicle speeds were also taken into consideration. Congestion was identified as a significant factor because speeds are often lower during periods of high traffic volume. Based on the earlier SR 7/41/48 RSS study, speeds were typically the highest between 12AM – 4AM. At these times, vehicle speeds are not affected by other vehicles due to low volumes. However, darkness may be another factor that affects vehicle speeds. During daylight hours, the earlier SR 7/41/48 RSS study found speeds were generally higher between 10AM – 3PM, which typically corresponds with a period of uncongested travel. Compared to overnight hours, vehicle speeds are more likely to be affected by other vehicles between 10AM – 3PM, but not as impacted by heavy congestion that limits motorists' ability to choose their travel speed. These two time periods, "Overnight" and "Midday Off-Peak", were chosen to quantitatively examine the effects of the speed display signs for all 23 data collection sites.

For each analysis time period (overnight and midday off-peak), the average and 85th percentile speeds were calculated for each site at the sign location and downstream of the sign for the before-after comparison. The standard deviations of average speeds were also calculated to compare before and after speed uniformity. One-tailed, two-sample t-tests were used for the statistical analysis to determine if the differences in before and after average speeds were statistically significant at the 95 percent significance level. It should be noted that due to the data collection methodology, which included speed bins that are not each 5 mph, the 10-mph pace speed (which is often used as a measure of speed uniformity) could not be readily calculated.

IV. Results

Table 3 below shows the before and after average speeds, 85th percentile speeds, and standard deviations at all sites at the sign and downstream of the sign for both the overnight and midday off-peak analysis periods. This table summarizes all before and after data; changes and statistical analyses are discussed further below.

Table 3: Before and After Speeds and Standard Deviations (mph)

Category	Site	Posted Speed Limit	Location	Average Speeds				85th Percentile Speeds				Standard Deviation			
				Overnight		Midday Off-Peak		Overnight		Midday Off-Peak		Overnight		Midday Off-Peak	
				Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Residential subdivision	1	25	Sign	-		18.3	18.8	-		22.3	22.8	-		3.6	4.0
			Downstream	-											
	2	25	Sign	-		17.9	16.7	-		22.6	19.5	-		3.8	3.0
			Downstream	-											
	3	25	Sign	19.8	18.8	21.4	19.3	23.6	23.9	25.9	23.0	4.5	4.4	4.4	3.8
			Downstream	23.8	22.6	24.5	24.2	31.7	26.5	29.9	28.8	7.4	4.5	5.1	4.9
	4	25	Sign	23.3	19.5	23.5	23.4	27.7	22.1	28.2	27.9	3.9	2.8	4.5	4.5
			Downstream	25.3	20.2	22.2	22.3	28.1	22.3	27.2	26.8	2.9	2.3	4.8	4.3
	5	25	Sign	-		21.2	20.7	-		25.9	25.3	-		5.0	4.4
			Downstream			21.6	21.8			26.3	26.1			4.9	4.3
	6	25	Sign	16.7	21.3	18.9	18.6	19.1	24.2	22.9	22.7	2.0	2.9	3.9	3.9
			Downstream	15.8	18.5	18.5	19.0	18.9	21.2	22.9	22.5	2.9	2.0	4.1	3.5
Municipal/town	7	25	Sign	31.5	28.9	29.9	28.0	35.0	33.1	34.6	32.3	3.9	4.6	5.0	4.6
			Downstream	28.7	26.7	25.1	24.2	33.1	31.3	30.4	28.8	4.7	5.0	5.7	5.3
	8	35	Sign	30.2	24.7	25.0	23.2	34.7	28.9	30.9	27.9	3.9	5.1	6.1	4.7
			Downstream	27.3	24.7	23.2	22.3	32.9	29.9	28.8	27.7	5.8	5.3	5.7	5.2
	9	25	Sign	31.5	33.7	27.6	29.6	37.4	42.9	33.0	35.8	7.0	7.2	5.6	6.1
			Downstream	31.3	31.5	27.1	27.4	37.3	38.9	31.3	31.6	5.4	6.2	4.5	4.5
Arterials – Kent & Sussex Counties	10	45	Sign	50.0	49.4	48.2	46.7	57.1	56.3	54.0	52.3	6.4	6.2	5.9	5.6
			Downstream	47.2	46.4	44.5	43.6	54.2	52.0	49.9	48.5	6.6	5.8	5.3	4.9
	11	40	Sign	40.4	40.1	39.4	38.8	47.1	47.3	44.9	43.8	6.6	7.2	5.6	5.3
			Downstream	41.0	42.2	40.9	40.0	46.2	48.8	46.2	44.8	6.1	6.6	5.3	5.0
	12	40	Sign	42.0	42.0	43.4	41.9	48.2	47.6	48.5	46.9	6.2	6.7	5.1	5.0
			Downstream	40.9	42.2	42.3	41.2	46.7	47.8	47.8	46.5	6.5	6.8	5.6	5.3
	13	35	Sign	30.3	32.5	30.3	29.2	36.3	39.1	36.6	35.0	7.4	7.0	6.5	6.5
			Downstream	28.7	29.5	27.4	27.2	37.3	38.1	33.5	33.5	8.0	8.4	6.0	6.2
	14	35	Sign	29.7	32.4	26.6	26.8	38.3	44.6	32.9	33.2	7.8	10.8	6.3	6.4
			Downstream	29.9	32.7	27.1	27.7	41.2	42.8	33.0	33.6	8.9	8.8	5.9	5.8

Table 3: Before and After Speeds and Standard Deviations (mph) (continued)

Category	Site	Posted Speed Limit	Location	Average Speeds				85th Percentile Speeds				Standard Deviation			
				Overnight		Midday Off-Peak		Overnight		Midday Off-Peak		Overnight		Midday Off-Peak	
				Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Arterials – New Castle County	15	40	Sign	46.2	45.6	41.6	42.1	52.9	52.4	45.8	46.4	6.2	6.3	4.4	4.5
			Downstream	46.2	46.5	38.3	40.4	53.0	53.5	44.6	46.1	6.5	6.3	6.5	5.8
	16	50	Sign	52.8	51.6	48.2	48.4	58.5	57.3	53.3	53.1	5.8	5.7	4.9	4.6
			Downstream	55.5	54.6	51.1	52.1	61.9	60.4	56.0	56.6	5.4	5.7	4.8	4.6
	17	35	Sign	40.8	40.1	31.3	31.3	49.0	47.8	36.4	36.7	8.0	7.1	5.3	5.5
			Downstream	43.6	43.3	40.5	40.2	50.8	50.2	46.4	46.0	6.7	6.5	5.7	5.7
	18	45	Sign	44.3	46.0	40.9	41.5	51.7	51.4	46.0	46.3	6.9	6.1	4.9	4.9
			Downstream	44.4	44.1	39.3	39.2	51.6	49.2	44.4	44.2	6.9	6.0	4.6	4.6
	19	35	Sign	-	43.0	-	38.9	-	49.4	-	43.8	-	6.1	-	4.8
			Downstream	50.3	49.2	44.9	45.7	56.0	54.9	49.8	50.5	5.0	5.4	5.1	4.8
	20	45	Sign	49.2	48.0	48.0	48.0	56.4	54.2	53.7	53.3	7.0	6.4	5.6	5.4
			Downstream	54.4	54.0	54.6	54.6	62.2	60.9	59.9	59.8	6.9	6.5	5.6	5.4
	21	50	Sign	53.9	54.4	51.5	52.9	61.0	62.1	56.5	57.8	7.2	6.6	5.0	5.0
			Downstream	53.7	54.4	51.1	53.1	61.5	61.9	56.4	58.1	7.2	6.6	5.2	5.0
	22	40	Sign	43.9	43.1	41.9	40.4	52.3	50.2	46.9	46.7	7.8	7.3	5.7	6.3
			Downstream	43.0	42.8	42.7	41.2	49.7	49.0	47.7	46.7	6.6	6.3	5.1	5.5
	23	40	Sign	42.8	42.3	43.2	42.2	50.6	49.3	49.2	48.9	6.9	7.2	5.9	6.3
			Downstream	44.6	43.4	44.4	42.2	51.5	49.2	49.6	47.8	7.1	5.9	5.2	5.5

Before/After Analysis Results

Table 4 and **Table 5** below show the changes in average speed, 85th percentile speed, and standard deviation among speeds – both at the sign and downstream of the sign. The colors in each cell correspond to the magnitude of the change; decreases are shown in green while increases are shown in red, with larger changes having darker colors.

Midday Off-Peak Before/After Analysis

The before and after results for the midday off-peak period between 10AM and 3PM are shown below.

Table 4: Midday Off-Peak Speed and Standard Deviation Changes (mph)

Category	Site	Average Speed Change		85th Percentile Speed Change		Standard Deviation Change	
		Sign	Downstream	Sign	Downstream	Sign	Downstream
Residential subdivision roads	1	+0.5	-	+0.6	-	+0.4	-
	2	-1.2	-	-3.1	-	-0.8	-
	3	-2.2	-0.2	-2.9	-1.0	-0.6	-0.2
	4	-0.2	+0.2	-0.3	-0.4	-0.0	-0.5
	5	-0.5	+0.2	-0.6	-0.2	-0.6	-0.6
	6	-0.3	+0.5	-0.2	-0.3	-0.1	-0.6
	Avg	**-0.6**	**+0.2**	**-1.1**	**-0.5**	**-0.3**	**-0.5**
Municipal/ town roads	7	-1.9	-0.9	-2.3	-1.6	-0.3	-0.4
	8	-1.9	-0.9	-3.0	-1.1	-1.3	-0.5
	9	+2.0	+0.3	+2.8	+0.3	+0.5	+0.0
	Avg	**-0.6**	**-0.5**	**-0.9**	**-0.8**	**-0.4**	**-0.3**
Arterials – Kent & Sussex Counties	10	-1.5	-0.9	-1.8	-1.4	-0.2	-0.4
	11	-0.6	-0.9	-1.1	-1.4	-0.3	-0.3
	12	-1.5	-1.1	-1.6	-1.3	-0.1	-0.3
	13	-1.1	-0.2	-1.6	-0.0	-0.1	+0.2
	14	+0.2	+0.6	+0.2	+0.5	+0.1	-0.1
	Avg	**-0.9**	**-0.5**	**-1.2**	**-0.7**	**-0.1**	**-0.2**
Arterials – New Castle County	15	+0.5	+2.1	+0.6	+1.5	+0.1	-0.6
	16	+0.1	+1.0	-0.2	+0.6	-0.2	-0.2
	17	-0.0	-0.3	+0.3	-0.4	+0.2	+0.0
	18	+0.5	-0.2	+0.3	-0.2	-0.0	-0.0
	19	-	+0.9	-	+0.7	-	-0.3
	20	-0.0	+0.0	-0.4	-0.1	-0.3	-0.2
	21	+1.4	+2.0	+1.4	+1.7	-0.0	-0.3
	22	-1.5	-1.6	-0.3	-1.0	+0.7	+0.4
	23	-1.0	-2.2	-0.4	-1.8	+0.4	+0.3
	Avg	**-0.0**	**+0.2**	**+0.2**	**+0.1**	**+0.1**	**-0.1**
Average (all sites)		-0.5	-0.1	-0.6	-0.3	-0.1	-0.2

There were both increases and decreases in the average and 85th percentile speeds after RSS installation. The magnitude of all midday off-peak speed changes was within approximately 3 mph, with most being less than 2 mph. The average of all average speed reductions was 1.0 mph at the sign and 0.8 mph

downstream of the sign. The average of all 85th percentile speed reductions was 1.3 mph at the sign and 0.8 mph downstream of the sign. In addition to showing that RSS's result in small speed reductions, these results also indicate that speed reductions downstream of the sign are lower (by approximately 20 percent on average) than those at the sign.

Residential subdivision roads, municipal/town roads, and arterials in Kent and Sussex Counties typically experienced speed decreases or negligible speed changes, while arterials in New Castle County typically experienced speed increases. Sites with the highest speed decreases at the RSS (Sites 3, 7, and 8) did not maintain the same magnitude of speed decrease downstream of the sign. Changes in standard deviation typically mirrored the speed changes where sites with increased speeds also had increased standard deviations and vice versa. A decreased standard deviation is desirable because a lower standard deviation indicates more uniform speeds.

Several of the sites studied are located near land uses or traffic control features that prior research (see literature review) showed could have a potential impact the effectiveness of the RSS's:

- Site 7 is located near a park. Based on the literature review, it may be expected that the RSS at Site 7 would be more effective at reducing speeds. Accordingly, the speed decreases at Site 7 are slightly greater than at most other sites, indicating the location near the park may impact the RSS effectiveness.
- Site 9 is located near a speed transition zone from 50 mph to 25 mph. The results show that average and 85th percentile speeds at Site 9 are 2 to 3 mph lower downstream of the RSS than at the sign location, which is substantially lower than other downstream speed reductions. This suggests the RSS may be more effective at lowering speeds at the speed transition zone, which is consistent with the findings in the literature review.
- Site 18 is located near an elementary school. The results showed speeds remained about the same downstream of the RSS following installation, but average speeds actually increased by 0.5 mph. While the literature review found that RSS's near schools were typically more effective at reducing speeds, the sign at Site 18 may not have performed like those in the literature review because the school is not visible from SR 41 (despite school signs and pavement markings); school grounds are obscured by houses and trees. The RSS is also upstream of those school signs and pavement markings.
- Sites 22 and 23 are the only arterials in New Castle County that experienced speed decreases. These signs are located on School Bell Rd, which serves mostly agricultural land uses with some residential land uses with far-spaced driveways. However, the signs are located within 300 feet of a community entrance with crosswalks and pedestrian crossing signs. The FHWA Desktop Reference of Potential Effectiveness in Reducing Speed discussed in the literature review found community entrances could impact RSS effectiveness, and the speed decreases in Sites 22 and 23 are consistent with this finding.

The speed data from all 23 sites were grouped (averaged) by posted speed limit to see if there was any difference in the effectiveness of the RSS. Within each speed limit category, the project team determined the average of each site's change in mean speed and change in 85th percentile speed both at the RSS and downstream (DS) of the sign. Results are shown in **Figure 2**.

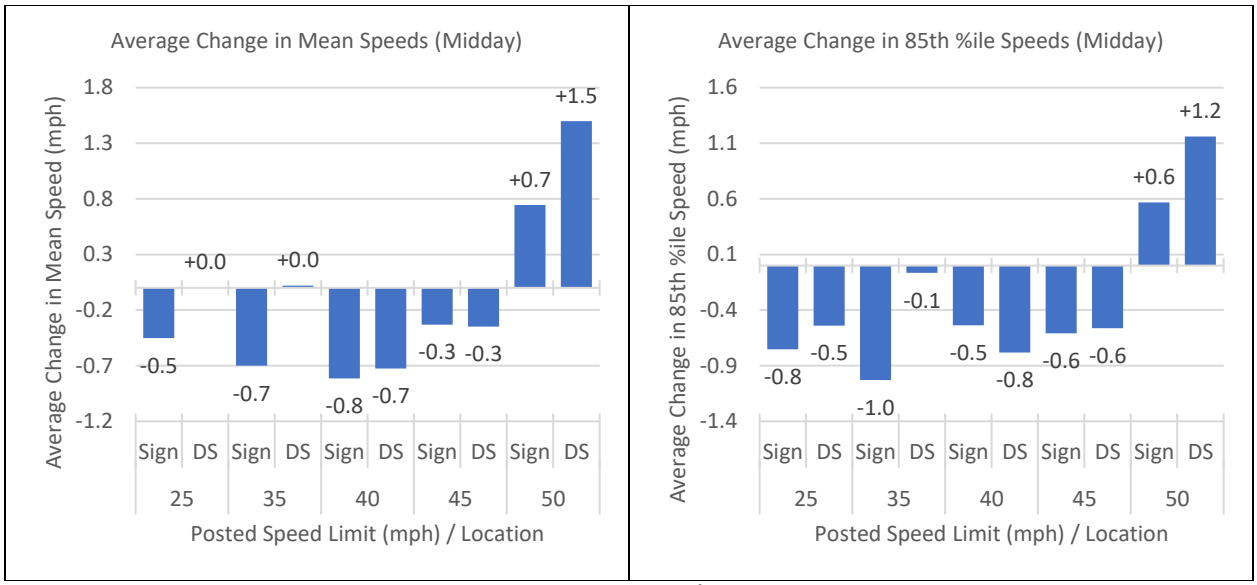

Figure 2: Before and After Mean and 85th Percentile Speeds (Midday)

Based on the charts presented in **Figure 2**, and consistent with the results presented in **Table 4** for individual sites, *on average*, "after" speeds are within 2 mph of "before" speeds for all posted speed limits. Sites with speed limits of 25 mph, 35 mph, 40 mph, or 45 mph experienced either no speed change or a slight decrease of up to 1 mph either at the sign or downstream, on average. There were only 2 sites with a speed limit of 50 mph, and when combined, the results show that speeds increased approximately 0.6 to 1.5 mph at the sign and downstream of the sign. The above figure shows that, *on average*, RSS's result in slightly reduced speeds for posted speed limits for 45 mph and below; however, these results are influenced by a combination of both increases and decreases at individual sites shown in in **Table 3**.

Overnight Before/After Analysis

To determine if RSS's have more or less effectiveness during the traditionally lowest-volume time periods, the project team evaluated speeds at all 23 sites between the hours of 12AM and 4AM. The before and after results for this overnight period are shown below. It is noted that the overnight period sample sizes were substantially smaller; therefore, trends are more susceptible to large fluctuations.

Table 5: Overnight Speed and Standard Deviation Changes (mph)

Category	Site	Average Speed Change		85th Percentile Speed Change		Standard Deviation Change	
		Sign	Downstream	Sign	Downstream	Sign	Downstream
Residential subdivision roads	1	-					
	2	-					
	3	-0.9	-1.2	+0.3	-5.3	-0.0	-2.8
	4	-3.8	-5.1	-5.6	-5.8	-1.1	-0.6
	5	-					
	6	+4.6	+2.7	+5.1	+2.3	+0.8	-0.9
	Avg	**-0.1**	**-1.2**	**-0.0**	**-2.9**	**-0.1**	**-1.4**
Municipal/ town roads	7	-2.6	-2.0	-1.9	-1.8	+0.7	+0.3
	8	-5.5	-2.6	-5.8	-3.0	+1.2	-0.5
	9	+2.2	+0.2	+5.5	+1.5	+0.2	+0.7
	Avg	**-2.0**	**-1.5**	**-0.7**	**-1.1**	**+0.7**	**+0.2**
Arterials – Kent & Sussex Counties	10	-0.5	-0.8	-0.8	-2.2	-0.2	-0.8
	11	-0.4	+1.3	+0.2	+2.6	+0.6	+0.6
	12	+0.0	+1.4	-0.6	+1.1	+0.5	+0.3
	13	+2.1	+0.8	+2.8	+0.8	-0.4	+0.3
	14	+2.7	+2.8	+6.3	+1.6	+3.0	-0.1
	Avg	**+0.8**	**+1.1**	**+1.6**	**+0.8**	**+0.7**	**+0.1**
Arterials – New Castle County	15	-0.7	+0.4	-0.5	+0.5	+0.2	-0.2
	16	-1.2	-0.9	-1.2	-1.5	-0.1	+0.3
	17	-0.7	-0.3	-1.2	-0.7	-0.9	-0.2
	18	+1.7	-0.4	-0.3	-2.4	-0.8	-0.9
	19	-	-1.0	-	-1.1	-	+0.4
	20	-1.2	-0.4	-2.2	-1.3	-0.6	-0.5
	21	+0.6	+0.7	+1.1	+0.4	-0.6	-0.6
	22	-0.9	-0.2	-2.0	-0.7	-0.5	-0.3
	23	-0.5	-1.2	-1.3	-2.3	+0.2	-1.2
	Avg	**-0.4**	**-0.4**	**-0.9**	**-1.0**	**-0.4**	**-0.3**
Average (all sites)		-0.3	-0.3	-0.1	-0.9	+0.1	-0.3

During the overnight period, municipal/town roads displayed the same pattern as during the midday off-peak period, where Sites 7 and 8 showed speed decreases and Site 9 showed speed increases. Residential subdivision roads also displayed the same pattern as the midday off-peak period with generally speed decreases at the sign location, except for Site 6 which experienced substantial speed increases both at the sign location and downstream of the sign. Both residential and municipal/town roads experienced speed changes of up to 6 mph, which are much larger than speed changes during the midday off-peak period. The larger magnitudes may be due to the smaller sample size. Sites 3, 4, 6, 8, 9, and 14 had approximately 20 vehicles or less in the before or after sample size. The patterns observed in both arterial categories (New Castle County and Kent or Sussex Counties) in the overnight period were the opposite of the patterns observed in the midday off-peak period. Arterials in Kent and Sussex Counties primarily experienced speed increases overnight (and decreases midday), while arterials in New Castle County primarily experienced

speed decreases overnight (and increases midday). However, most speed change magnitudes were within 3 mph during the overnight period on the arterials, with the exception of Site 14 where the 85th percentile speed was 6 mph higher during the after period at the sign location.

Downstream speed reductions were typically similar to speed reductions at the sign during the overnight period. The average of all average speed reductions was 1.6 mph at the sign and 1.3 mph downstream of the sign. The average of all 85th percentile speed reductions was 1.9 mph at the sign and 2.3 mph downstream of the sign. The overnight speed reductions were slightly larger than the midday off-peak speed reductions, but are still relatively small in terms of the magnitude of change.

As with the midday off-peak, sites near land uses that impact RSS effectiveness during the overnight period were examined. Site 7 again shows the presence of a park resulted in larger speed decreases than most other sites (although it is noted the upstream sign location also experienced a speed reduction of 2.3 mph, indicating the overnight speed reduction may have been due to external factors instead of the RSS). Site 9 again shows that speeds are higher as vehicles enter the 50 mph to 25 mph speed transition zone but are substantially lower downstream of the RSS. The overnight results at these sites match the literature review findings that RSS's may be more effective when located near parks and speed transition zones. Meanwhile, Site 18 did not show substantially higher speed decreases as was the case during the midday off-peak period, possibly because the elementary school is not visible from the roadway.

The overnight speed data from all 23 sites were grouped (averaged) by posted speed limit to see if there was any difference in the effectiveness of the RSS. Within each speed limit category, the project team determined the average of each site's change in mean speed and change in 85th percentile speed during the overnight period both at the RSS and downstream (DS) of the sign. Results are shown in **Figure 3**.

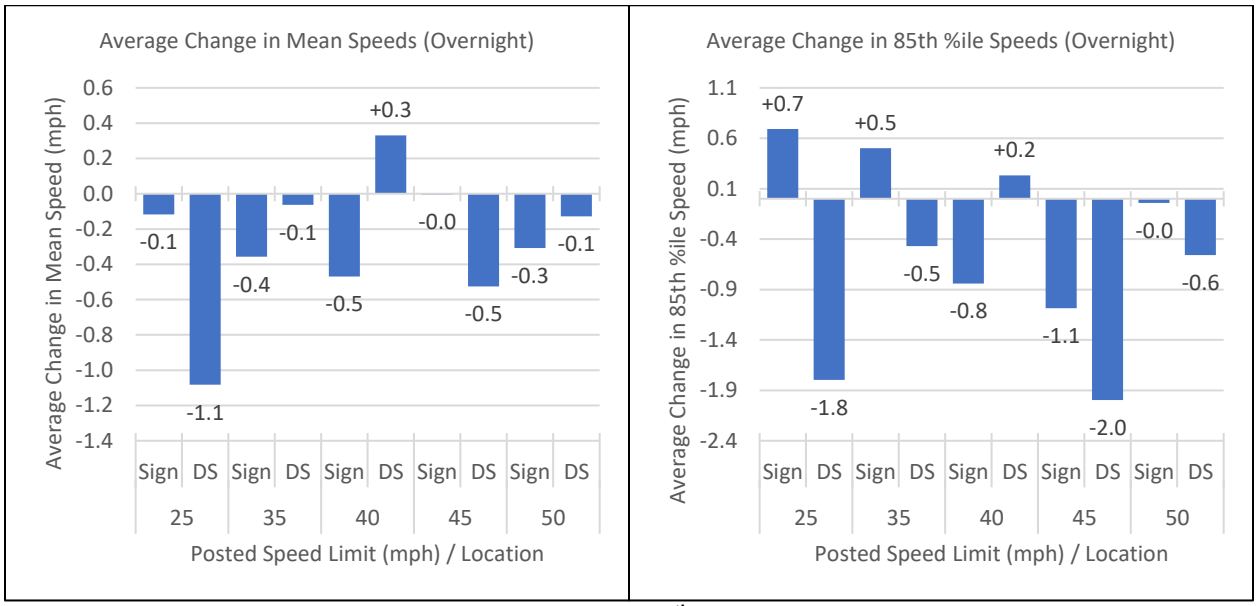

Figure 3: Before and After Mean and 85th Percentile Speeds (Overnight)

As with the midday off-peak results, *on average*, the overnight speed changes were less than 2 mph. In general, average differences were negative, indicating an overall speed reduction for most posted speed limits. The exception was for 40 mph, where the change in average speeds was positive downstream of the sign location. 85th percentile speed changes were more variable. Sites with a speed limit of 25 mph experienced a relatively large speed reduction downstream of the sign, on average, although it is noted that many sites with a speed limit of 25 mph had very small sample sizes. As with the midday off-peak results, the overnight average mean speed changes are influenced by both large increases and decreases at

individual sites that, taken together, average out to a slight average reduction. There is no clear pattern in the change in 85th percentile speeds when grouped by speed limit.

Statistical Analysis Results

While the previous section showed the magnitude of the speed changes, **Table 6** and **Table 7** show the statistical significance of the average speed changes. One-tailed, two-sample t-tests were performed to determine if reductions in average speeds at each site were statistically significant at a 95 percent confidence level. It is noted that t-tests with large sample sizes, such as the data obtained for this study, will often result in statistical significance, even if the speed reduction is small in magnitude. Speed increases are shaded in red and speed decreases are shaded in green, with darker colors indicating larger magnitudes. Sites with statistically significant speed changes are shaded in blue.

Midday Off-Peak Statistical Analysis

Table 6: Midday Off-Peak Average Speed Change Statistical Significance

Category	Site	Sign Location		Downstream Location	
		Speed change (mph)	Statistically significant?	Speed change (mph)	Statistically significant?
Residential subdivision roads	1	+0.5	No	-	
	2	-1.2	No	-	
	3	-2.2	Yes	-0.2	No
	4	-0.2	No	+0.2	No
	5	-0.5	No	+0.2	No
	6	-0.3	No	+0.5	No
Municipal/ town roads	7	-1.9	Yes	-0.9	Yes
	8	-1.9	Yes	-0.9	Yes
	9	+2.0	Yes	+0.3	Yes
Arterials – Kent & Sussex Counties	10	-1.5	Yes	-0.9	Yes
	11	-0.6	Yes	-0.9	Yes
	12	-1.5	Yes	-1.1	Yes
	13	-1.1	Yes	-0.2	No
	14	+0.2	No	+0.6	Yes
Arterials – New Castle County	15	+0.5	Yes	+2.1	Yes
	16	+0.1	No	+1.0	Yes
	17	-0.0	No	-0.3	Yes
	18	+0.5	Yes	-0.2	No
	19	-		+0.9	Yes
	20	-0.0	No	+0.0	No
	21	+1.4	Yes	+2.0	Yes
	22	-1.5	Yes	-1.6	Yes
	23	-1.0	Yes	-2.2	Yes

Approximately 40 percent of sites experienced a statistically significant speed decrease, either at the sign location or downstream of the sign. However, 20 percent of sites at the sign and 30 percent of downstream sites experienced a statistically significant speed increase, while the remaining 40 percent of sites at the sign and 30 percent of downstream sites experienced a speed change that was not statistically significant. The analysis did not show RSS's provide consistent statistically significant speed reductions as less than half the sites showed such reductions. Furthermore, the small speed decreases (less than 2 mph) are not practically meaningful, regardless of their statistical significance. It should be noted that very large sample sizes are likely contributing to the statistical significance, as sample sizes were as high as 26,000 vehicles.

Speed changes in residential subdivisions were typically not statistically significant, while speed changes on municipal/town roads and on arterials in Kent and Sussex Counties were typically statistically significant. There was no clear pattern on statistical significance on arterials in New Castle County.

Site 7 (near a park) showed statistically significant speed reductions while Site 18 (near a school) showed a statistically significant speed increase during the midday off-peak period.

Overnight Statistical Analysis

Table 7: Overnight Average Speed Change Statistical Significance

Category	Site	Sign Location		Downstream Location	
		Speed change (mph)	Statistically significant?	Speed change (mph)	Statistically significant?
Residential subdivision roads	1	-			
	2	-			
	3	-0.9	No	-1.2	No
	4	-3.8	No	-5.1	Yes
	5	-			
	6	+4.6	Yes	+2.7	No
Municipal/ town roads	7	-2.6	Yes	-2.0	Yes
	8	-5.5	Yes	-2.6	Yes
	9	+2.2	No	+0.2	No
Arterials – Kent & Sussex Counties	10	-0.5	No	-0.8	No
	11	-0.4	No	+1.3	No
	12	+0.0	No	+1.4	No
	13	+2.1	No	+0.8	No
	14	+2.7	No	+2.8	No
Arterials – New Castle County	15	-0.7	No	+0.4	No
	16	-1.2	Yes	-0.9	Yes
	17	-0.7	No	-0.3	No
	18	+1.7	Yes	-0.4	No
	19	-		-1.0	Yes
	20	-1.2	Yes	-0.4	No
	21	+0.6	No	+0.7	No
	22	-0.9	No	-0.2	No
	23	-0.5	No	-1.2	No

During the overnight period, there were fewer sites with statistically significant speed changes. About 20 percent of sites at the sign and 25 percent of downstream sites experienced a statistically significant speed decrease. About 10 percent of sites at the sign and no downstream sites experienced a statistically significant speed increase. About 70 percent of sites at the sign and 75 percent of downstream sites experienced a speed change that was not statistically significant. As with the midday off-peak period, the analysis did not show RSS's provide consistent statistically significant speed reductions as only 20 to 25 percent of the sites showed such reductions. Although there were some comparatively larger speed changes of approximately 5 mph, most speed changes that were statistically significant changes were smaller in magnitude, in the range of 1 to 3 mph, and were likely due to the large sample sizes. Arterials in Kent and Sussex Counties did not experience statistically significant speed changes during the overnight analysis period. There were no clear patterns of statistical significance on residential subdivision roads, municipal/town roads, or arterials in New Castle County. As with the midday off-peak period, the downstream statistical significance was usually the same as the statistical significance at the sign.

Site 7 (near a park) showed statistically significant speed reductions while Site 18 (near a school) showed a statistically significant speed increase during the overnight period.

V. Discussion

Based on the speed data collected during the midday and overnight periods, it is apparent that RSS's provide mixed impacts on vehicle speeds. Overall, **speed changes were typically less than 2 mph, and in some locations, speeds even increased after sign installation**. RSS's often resulted in statistically significant speed changes; however, despite being statistically significant, the magnitudes of speed changes were too small to be practically meaningful. Additionally, some changes were statistically significant speed *increases* instead of the desired decreases. Downstream of the RSS's, speed reductions were typically smaller than those at the RSS, which indicates the effectiveness of the signs are limited as drivers move away from the signs.

Overall, there was no consistent pattern of RSS effectiveness across all sites. Therefore, patterns were then searched for by grouping sites together based on several different variables. The patterns (or lack of patterns) observed among these groupings are described below:

- **RSS's near a park, speed transition zone, or community entrance resulted in slightly higher speed reductions than those at other sites**. This pattern is consistent with results from the literature review which found that RSS's were more effective where drivers understand the need to slow down. The exception was the RSS near a school in Site 18, which did not result in a higher speed reduction. The counterintuitive results at Site 18 may have been because the school grounds are not visible from the roadway, so the need to slow down may not be as apparent to drivers.
- RSS's within the same roadway category (functional classification and geographic location in Delaware) occasionally displayed similar trends; however, the trends were not consistent during the different midday off-peak and overnight analysis periods:
    - RSS's on arterials in Kent and Sussex Counties and municipal/town roads typically resulted in speed decreases during the midday off-peak period and speed increases during the overnight period.
    - RSS's on arterials in New Castle County experienced the opposite: speed increases during the midday off-peak period and speed decreases during the overnight period.
    - RSS's on residential/subdivision roads displayed no consistent patterns of effectiveness during either analysis period.
    - There were no patterns within roadway categories that were consistent between both analysis periods.
- **RSS's generally showed no consistent speed reduction patterns when sites were grouped by speed limit**, indicating that speed limit may not be a factor in effectiveness. Average speed changes were typically small reductions that were the result of averaging both large speed increases and large speed decreases at individual sites.

Because there are no patterns of RSS effectiveness when grouping sites by functional classification, geographic area, and speed limit, these variables may not need to be considered when deciding if an RSS should be installed at a certain site. Based on this research, these variables did not help predict if an RSS will be effective. However, proximity to features where drivers understand the need to reduce their speeds (such as parks, speed transition zones, community entrances, and others discussed in the literature review) may be more appropriate because RSS's were found to be slightly more effective near these features.

Trends in the changes in standard deviation (a proxy measure of speed uniformity) generally mirrored speed change trends. Just as there was no consistent pattern of speed reductions across all sites, there was no consistent pattern of standard deviation reductions, and therefore better speed uniformity, across all sites.

Based on the before and after mean speeds, 85th percentile speeds, and standard deviations, the RSS's do not appear to provide a consistent pattern of significant speed reductions or improved speed uniformity. **Overall, the results of this study show that RSS's may result in a minor (typically less than 2 mph) reduction in speeds, and the minor reduction in vehicle speeds is likely to diminish as vehicles proceed further past the sign. Furthermore, RSS's are likely to be slightly more effective at reducing speed and/or improving speed uniformity at sites where drivers understand the need to reduce their speeds, such as school zones, parks, and speed transition zones.**

VI. Conclusions and Recommendations

A review of 23 sites in Delaware found that RSS's do not provide consistent statistically significant speed reductions. They also do not consistently reduce 85th percentile speeds or improve speed uniformity. Speed and standard deviation changes after RSS installation were found to be relatively small in magnitude and could be either increases or decreases.

Although the results of this study did show some statistically significant decreases and increases in average speeds, the magnitude of increases were generally small (1 to 3 mph). Additionally, where there were speed reductions, those reductions typically diminished further from the sign. RSS's were found to be slightly more effective at consistently reducing speed at locations where drivers understand there is an underlying need to reduce speed, such as school zones, parks, and speed transition zones. Therefore, RSS's may be one tool to consider if a community group or legislator would like to install the signs as a low-cost treatment.

The current study evaluated the effectiveness of conventional RSS's that display a motorist's travel speed, either as a standalone unit or alongside a static speed limit sign. Other forms of RSS's have been observed in other states and municipalities that utilize pictographs or unique messaging to reinforce proper speed selection. Future research could consider whether RSS's that utilize such pictographs and/or unique messaging can provide greater or more consistent speed reductions compared to the conventional RSS's studied in this project. These new RSS's would display one pictograph or unique message if the speed is at or below the posted speed limit and another pictograph or unique message if the measured speed is above the posted speed limit.

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