Michigan Department of Transportation

Evaluation of R1-6 Gateway Treatment Alternatives for Pedestrian Crossings

Final Report

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List of Acronyms

Average Daily Traffic	ADT
Baseline	BL
Federal Highway Administration	FHWA
Institute of Transportation Engineers	ITE
Manual on Uniform Traffic Control Devices	MUTCD
Michigan Department of Transportation	MDOT
Miles per Hour	mph
Minnesota Department of Transportation	MNDOT
National Cooperative Highway Research Program	NCHRP
National Highway Traffic Safety Administration	NHTSA
Pedestrian Hybrid Beacon	PHB
Rectangular Rapid Flashing Beacon	RRFB
Western Michigan University	WMU

EXECUTIVE SUMMARY

The Gateway configuration of R1-6, in street signs, has been documented to produce a marked increase in driver yielding to pedestrians over the use of a single sign. Figure a shows a Gateway configuration with a sign on the centerline, a signs at the edge of the road, and signs on the white lane lines that divides lanes. In 2013, the Michigan Department of Transportation (MDOT) initiated a multi-year study with Western Michigan University (WMU) in order to evaluate factors related to the efficacy of a gateway treatment using R1-6 signs (gateway treatment); the long term effects of permanent installations; configurations that contribute to the effectiveness of the treatment; and the long-term survival of the treatment.

Figure a. A picture of a Gateway configuration of R1-6 signs.

A series of studies were completed in order to determine the effectiveness of the in-street sign gateway treatment, determine where they should be used, and determine the cost benefits of using the in-street sign gateway treatment including operation, maintenance and replacement costs and comparative analysis with the RRFB and Hybrid Beacon. In order to address these objectives, the WMU team conducted a number of activities; each is captured as an individual chapter of this report. Although each of these interventions were only compared at a relatively small number of sites, each condition was introduced multiple times at each site producing multiple replications of each condition, the obvious large changes in driver behavior, and the consistency of results at these sites suggest that these finding are robust. This conclusion is supported by the statistical analysis reported in the appendix to this report. All of the configurations tested increased driver yielding behavior.

One hypothesis examined was that the narrowness of the gap between the signs would be inversely related to treatment effect size. This hypothesis was confirmed with narrower gaps leading to larger increases in driver yielding right-of-way to pedestrians. Another hypothesis tested was that the sign message itself had little influence on driver yielding behavior. This hypothesis was found to be incorrect; a gateway configuration consisting of all blank signs was significantly less effective than the Gateway configuration with the message present (standard R1-6 signs).

A configuration analysis also showed that the position of the sign is a critical factor influencing driver yielding behavior. Not all positions used in isolation resulted in the same degree of driver yielding right-of-way to pedestrians. Signs placed on the white lane line alone exerted more control over driver yielding behavior than signs placed at the edge of the roadway positions alone at all sites and both types of placements produced less yielding than the full Gateway treatment. However, the partial effects produced by all of the partial gateway configurations shows that if a sign is hit during a season and not replaced until the following year when all the signs are reinstalled after winter, the remaining signs would still be of benefit to pedestrians for the remainder of the season.

Speed data collected at one site showed the Gateway treatment is associated with large speed reductions even when pedestrians were not present at the crosswalk and that drivers began slowing at the dilemma zone. These data suggests that the speed reduction is likely gradual. This is an important finding because reduced speed gives driver more time to respond to avoid a crash. This finding requires further replication.

Although these studies and previous conducted research (2) demonstrate that the gateway treatment produced changes in driver yielding behavior at crosswalks on multilane roads that rivals treatments that are one and two orders of magnitude more expensive to install, it is also important to show that this treatment will not require excessive maintenance efforts. In areas requiring snow removal, the signs would need to be removed during the winter months. Most of the signs tested can be removed and reinstalled quickly after the initial installation. Although in-street signs are designed to rebound after being struck, sign survival with multiple strikes would be expected to be an issue.

Two configurations were tested that should greatly increase sign survival only produced moderate decrements in the efficacy of the Gateway treatment. The first configuration tested involved installing signs on top of the curb face rather than in the gutter pan (required FHWA permission to experiment). Placing signs on top of the curb was only associated with only a small reduction in the effectiveness of the treatment. Signs on top of the curb face are less likely to be struck than signs placed in the gutter pan and do not present a problem for sweepers nor do they introduce potential drainage issues.

The most vulnerable element of the sign configuration is the signs placed on white lines separating lanes carrying traffic in the same direction. The substitution of a robust flexible yellow green delineator device for the R1-6 sign would be expected to increase the survival of signs placed on the white lane lines. A delineator was selected that was tested by the Texas Transportation Institute and found to survive 100 strikes at 60 mph. This type of a device should have an even longer lifespan on urban roads with speed limits of 35 mph or less. Data reported in Chapter 2 shows that the use of a robust delineator only produced a modest reduction in the effectiveness of the Gateway treatment. If there is a median or refuge island the use of curb top placement and use of a delineator at the lane line covers all installations with devices that should provide a trouble free installation for many years.

Most of the application studied in an earlier MDOT study examined the efficacy of the Gateway treatment at crosswalks on arterial or collector roads and at uncontrolled crosswalks located at the intersection with a stop controlled minor road. A map of locations used for this study is provided in Chapter 4. This research also evaluated the Gateway treatment in a variety of new crosswalk applications, including traffic circles, roundabouts; interstate entrance ramps, and trails crossings. The results of these studies showed: the Gateway treatment was moderately effective at the traffic circle and two roundabout locations, particularly at crosswalks exiting the roundabout. The application at interstate entrance ramps only produced marginal increases in yielding behavior. The Gateway is therefore not recommended for this type of application. The Gateway was highly effective at one of the two trail crossings but only moderately effective at the second crossing that had a higher operating speed. Another study replicated an earlier finding that the Gateway treatment can increase yielding at an RRFB site to very high levels. The final study in this series found that treating only one crosswalk leg at an intersection with a minor road could improve yielding at the untreated crosswalk leg.

Permanent installation of these sites provided preliminary evidence of the long-term persistence of increased driver yielding right-of-way to pedestrians at Gateway locations and the long-term survival of the Gateway treatment. Results only demonstrated that the signs maintained their effectiveness in Ann Arbor over two months and at the sites in the southwestern side of the state for three-months because these signs needed to be removed for winter. Because the signs were only installed for two months in Ann Arbor and only three months at the sites in southwest Michigan, supplemental data will be required in order to provide clear evidence that the effects persist over time. Preliminary data on sign survival indicate that Gateway signs mounted in the roadway on installable curb bases may be more robust than signs installed flush with the roadway and that the robust flexible delineator installed on a lane line can sustain many hits but may not survive for an entire season at sites with higher speeds and high ADT.

The final chapter provided information on materials and approximates installation costs for each of the elements of the Gateway treatment. These data show that it is a relatively inexpensive treatment. Most items can be removed easily in winter and reinstalled easily in the spring. Estimated removal and reinstallation costs were also provided. The final chapter provides an overview of the conclusions reached by the research team as part of each task of the multi-year study and cost data for various Gateway pedestrian crossing configurations.

INTRODUCTION

In 2013, the Michigan Department of Transportation (MDOT) initiated a multi-year study with Western Michigan University (WMU) in order to: 1. Evaluate factors related to the efficacy of a gateway treatment using R1-6 signs (gateway treatment), 2. Determine the long-term effects of permanent installations, and 3. Examine configurations that contribute to the effectiveness of the treatment.

As MDOT would like to increase its focus on reducing the number of pedestrian crashes in Michigan as part of the Toward Zero Deaths statewide safety campaign, the WMU/T.Y. Lin International team (hereafter referred to as the "WMU team") proposed the following objectives:

1. Determine the effectiveness of driver compliance with gateway treatment in comparison to the rectangular rapid flash beacon (RRFB) and the pedestrian hybrid beacon (PHB).

2. Determine where and when the gateway treatment should be used and the most effective, configurations of the R1-6 signs.

3. Determine the cost benefits of using the gateway treatment including operation, maintenance and replacement costs with the RRFB and PHB.

In order to address these objectives, the WMU team conducted a number of activities; each is captured as an individual chapter of this report. The following provides an outline of the individual chapters and thereby the actions taken as part of this multi-year study:

Chapter 1 – Configurations Influencing the Efficacy of the Gateway Treatment.
Chapter 2 – Evaluation of Configurations that Improve the Gateway Treatment Survival.
Chapter 3 – Evaluation of the Gateway Treatment Configuration in Various Applications.
Chapter 4 – Potential Roadway Factors Influencing the Efficacy of the Gateway Treatment.
Chapter 5 – Long Term Efficacy and Survival of the Gateway Treatment.
Chapter 6 – Costs Associated with Installation and Maintenance of the Gateway Treatment.
Chapter 7 – Conclusions.

LITERATURE REVIEW

Traditional Applications of the In-Street Sign

Although pedestrian crashes account for only 1 percent of reported motor vehicle crashes in the United States, they account for 14 percent of fatal crashes (1). Zegeer et al. (2) compared crashes at 1,000 marked and 1,000 matched unmarked crosswalks in 30 U.S. cities. The study found no significant difference in crashes between marked and unmarked crosswalks at sites with one lane in each direction, but higher crash rates at marked crosswalks on multilane roads with an uncontrolled approach when the road had average annual daily traffic (AADT) above 12,000 without a raised median, and above 15,000 with a raised median. They also observed a higher incidence of multiple threat crashes at these sites. These data show the need for low cost countermeasures to increase yielding to pedestrians at crosswalks on multilane roads with moderate to high levels of average daily traffic (ADT). Current treatments include the rectangular rapid flashing beacon (RRFB), which costs around $20,000 per installation and the pedestrian hybrid beacon (PHB) that costs $100,000 per installation. Both these treatments should be used with advance yield or stop markings to encourage drivers to yield further from the crosswalk. When these treatments are used together, the RRFB or PHB increases yielding while the advance stop and yield markings primary influence safety by reducing the probability of a multiple threat crash. It should be noted that the costs associated with the installation of the RRFB and PHB treatments limit their deployment.

One way to improve the safety at pedestrian crossings is the use of the in-street sign. This sign is installed in the roadway and reminds drivers that it is the law to yield to pedestrians within crosswalks. One advantage of this device is it requires no action from the pedestrian to activate the device and it is therefore active for every crossing. Many studies have documented that placing "Yield to Pedestrian Signs" in the roadway can increase the percentage of motorists yielding to pedestrians (3,4) Huang, Zegeer, and Nassi (3) evaluated the effects of in-street "STATE LAW: YIELD TO PEDESTRIANS IN YOUR HALF OF ROAD[1]" signs placed in the middle of the crosswalk on driver yielding behavior at 7 locations. Yielding increased from 70% before the signs were installed to 81% after the signs were installed. The in-street sign produced larger effects than an overhead crosswalk sign or a pedestrian regulatory sign in this study. The authors also noted that there were reports that some motorists ran over the in-street signs intentionally. Although in-street signs are designed to recover when struck by vehicles, repeated strikes, or high-speed strikes can permanently damage these signs.

In-street signs were also evaluated (4) in a study jointly funded by the Transit Cooperative Research Program and the National Cooperative Highway Research Program that compared several treatments to improve motorist yielding to pedestrians at unsignalized intersections. The research team collected data on motorist yielding behavior at 42 crosswalks in different

[1] It should be noted that Michigan does not have a state law on yielding to pedestrians in crosswalks, instead local ordinances or local adoption of the Uniform Traffic Code need to address ROW in Michigan (other than at signalized intersections).

regions of the United States. The results indicated that in-street signs were associated with yielding rates of 87% on two lane roads. In-street signs were superior to yellow overhead flashing beacons, pedestrian crossing flags, and in-roadway warning lights. Only a red signal or red beacon devices produced higher yielding behavior than in-street signs. The results of the study showed in-street signs to be highly cost effective in increasing yielding behavior at crosswalks that traverse roads with one lane in each direction. Data also showed that in-street pedestrian signs performed equally well on roads with 25 and 30 mph speed limits. They were not evaluated on roads with higher speed limits. The authors also concluded that these signs were not effective on multi-lane roads and only recommended treatments with a red indication at these sites.

One study examined the effect of placing these signs on the centerline at the crosswalk line, 20 feet in advance of the crosswalk line, and 40 feet in advance of the crosswalk line at three crosswalks on driver yielding behavior on two-lane roads (5). At one of the three locations placing the sign at the crosswalk line or installing three signs was significantly more effective than installing the sign at 20 or 40 ft in advance of the crosswalk. At another site installing the sign at the crosswalk line or installing all three signs was significantly more effective than installing the sign 40 ft in advance of the crosswalk. Overall it appeared that installing the signs at the crosswalk line was as effective or more effective than installing the sign in advance of the crosswalk or installing the signs at all three distances from the crosswalk. At one of the three sites, pedestrians were often trapped in the middle of the road during the baseline condition; the in-street sign was highly effective in reducing the number of trapped pedestrians regardless of where it was placed. It should be expected that large increases in yielding should be associated with reductions in the percentage of pedestrians trapped in the middle of the roadway wherever this problem exits. These data suggest that the in-street signs are most likely effective because the placement in the street is particularly salient to drivers.

Another study (6) replicated the Van Houten, et. al. (5) study by comparing placing signs at the crosswalk line, with placing them 30 ft, 60ft, 90 ft and 120 ft in advance of the crosswalk line on 8 two-lane roads. They found that the in-street sign placed at the crosswalk was more effective than signs placed in advance of the crosswalk. They also examined whether the installations of an in-street sign influenced vehicle speed and found the in-street signs significantly lower vehicle speeds at the crosswalk in both directions at 7 of the 8 sites, and in one direction at the remaining site. These results are promising, however all sites had very low posted speed limits (25 mph at 5 sites and 20 mph at the 3 remaining sites). Kannel, Souleyrette, & Tenges (7) also reported a small reduction in speed at a single conventional in-street sign location posted at 30 mph.

Evaluation of a Gateway Installation on Multilane Roads

One limitation of the in-street sign is its failure to produce high levels of yielding on multilane roads. Shurbutt, Van Houten, Turner, and Huitema (8) documented how the efficacy of another pedestrian crosswalk countermeasure, the RRFB, could be increased by introducing a third device on the median island producing a type of "gateway" visual effect for approaching drivers. Bennett and Van Houten (9) used a gateway configuration of the in-street sign (the use of a sign on the lane line and two roadway edge signs - three signs for each two lane approach to the crosswalk) produced a marked improvement in yielding at multilane uncontrolled crosswalks that was comparable to those produced by an RRFB or PHB (10, 11). One reason the gateway in-street sign configuration was so effective may have been the perceived narrowing of the roadway produced by adding signs on both sides of the road outside the lanes even though the width of the travel way itself was not actually narrowed. It is also likely that three signs were more visible than one sign, particularly if vehicles ahead of a motorist approaching the crossing blocked the motorist's view of the location of the single sign.

It is also possible that the gateway effect acquired captures driver attention independent of a perceived narrowing effect. This rationale is supported by research showing the gateway configuration of the RRFB also produced a marked effect even though beacons were not in the placed in the roadway. In-street signs may also provide better delineation of the edge of the roadway when they are present. Specifically, the boundaries of the road are extended vertically via the signs. A driver may ignore the boundaries of the road while driving. However, when the visual boundaries are made more salient, it may cause drivers to slow down. This effect may occur because it reduces the narrowing of perspective that occurs when someone is driving making it more likely the driver will attend to a pedestrian starting to cross at the edge of the road.

Because the data reported by Bennett and Van Houten (9) were collected over months, they also captured the effectiveness of the intervention over time. However, it is not known whether these results will be sustained over longer periods of time. Research is needed to address this question as well as data on how the in-street sign performs at night.

Installation of the In-Street Sign at RRFB and PHB Sites

Data collected by Dr. Van Houten for MDOT (12) also revealed that the RRFB and PHB produced poorer yielding results in Michigan than data collected in a large-scale FHWA evaluation. Data collected in a review conducted by Dr. Van Houten also showed that this problem was not unique to Michigan sites with similar results reported in Kansas and Portland, Oregon (13,14). It is likely the poorer results are a function of the smaller number of units installed in some test communities and the relatively lower level of outreach efforts at sites that were not part of the FHWA research project. Data from the Michigan sites seem to confirm this finding. Data collected by in the MDOT study also suggest that the use of the in-street sign at new RRFB and PHB sites may be a relatively low cost alternative to large-scale outreach efforts. Bennett and Van Houten (9) found that a single in-street sign at RRFB and PHB sites in Michigan produced higher levels of yielding than RRFB or PHB treatments used alone.

It is important that additional studies examine the interaction of the in-street sign with the RRFB and PHB in order to determine why it is effect. One question that needs to be addressed is whether drivers learn to respond to better to the RRFB and PHB installations without the in-street sign after it has been paired for a period of months with the in-street sign.

The Role of Advance Stop or Yield Sign and Markings

Whenever drivers yield right of way to pedestrians on multilane roadways and stops close to the crosswalk line, they can screen the view of pedestrians from vehicles approaching in adjacent lanes, increasing the probability of multiple threat crash. A series of experiments (15, 16, 17, 18, 19) has demonstrated that the combination of advance yield/stop markings along with "Yield/Stop Here for Pedestrian" signs in advance of the crosswalk reduced driver/pedestrian evasive conflicts by 67% to 87% and produced a large increase in the distance motorists yielded in advance of the crosswalk. These data strongly support always using advance markings at uncontrolled crosswalk sites associated with increased risk of multiple threat crashes. These sites include those with ADT above 12,000 without a raised median and 15,000 with a raised median.

Questions to be Addressed by Further Research

The results of this research will assist MDOT in determining how to maximize pedestrian safety benefits with limited financial resources. Evaluating the impact of the in-street sign gateway treatment in a variety of different crossing applications could help identify potential applications of this treatment option. It is also important to determine how much the visual narrowing effect of the gateway treatment contributes to the effect and whether similar effects could be obtained by using delineators without the in-street sign message. Another issue that requires study is how to extend the useful life of in-street signs. One way to reduce damage to these signs is to place them at roadway locations where they are less likely to be hit. There are a number of placement strategies that could extend the life of these signs, which should be evaluated. Additional research should determine the conditions where the in-street sign gateway treatment can be substituted for more expensive RRFB and PHB treatments.

New trends in traffic engineering research have focused on determining the conditions under which a treatment is effective, and how to optimize the treatment. For example in two recently funded Federal Highway Administration (FHWA) studies, Ellis and Van Houten (20) documented how matching countermeasures to crash types in Miami could reduce pedestrian crashes in high crash zones by 50%, and Shurbutt, Van Houten, Turner, and Huitema (8) documented how the efficacy of the RRFB could be increased by fine tuning how it is installed and how it is operated. A recently published National Highway Safety Administration (NHTSA) funded study (21) has also demonstrated how the in-street sign could be used as part of an pedestrian right-of-way enforcement program to produce a culture shift in yielding right-of-way to pedestrians on a city wide basis. It has been long know that results may vary following the implementation of signage and traffic control devices. In order to maximize results practitioners need to better understand where, and how to implement these devices. It is also important to determine what variables influencing the life span or survival of these signs since this impacts replacement and maintenance costs. Research on the in-street sign should address these issues as well as examine the life span of these signs using different strategies to develop guidelines to best insure installations are practical as well as cost effective

SURVEY ON USE OF R1-6 SIGN

A survey was sent out on our behalf from FHWA to states participating in the pooled fund research program. The survey asked respondents to identify the state, an estimate of how many in-street pedestrian crossing sign (R1-6, or R1-6a) have been installed in their state, whether they were aware if anyone had performed a crash analysis of the effectiveness of these signs, and if a crash analysis had been performed, contact information to learn more about the results of the study. We received feedback from the following 11 states: Florida, Iowa, Kansas, Minnesota, Missouri, Nebraska, New Hampshire, North Carolina, Oregon, Pennsylvania, and South Carolina. None of the state pool fund coordinators were aware of any research on these signs. With the exception of Pennsylvania, Minnesota, New Hampshire, and North Carolina, state officials stated they only reported the number installed on state roads and did not attempt to estimate the number of signs installed by cities and municipalities. Therefore, this list should be considered to be a conservative estimate because in most cases they only included those installed on state roads. Pennsylvania mentioned that they paid for all in-street signs installed by municipalities in the state since 2001, and therefore, the number they provided can be viewed as accurate. New Hampshire mentioned that their number included in-street signs purchased for municipalities but that they had no knowledge of additional signs municipalities may have directly purchased and installed. Table A-1 shows the results of the pooled fund survey. The state of Pennsylvania had the largest number in street signs (7500). It is not known whether any of these signs are installed on multilane roads, and there is no indication whether any of these signs are installed in a gateway configuration.

Table A-1. The number of in-street sign sites reported by 11 pool fund states.

State	Number of Installations
Florida	24
Iowa	15
Kansas	A few
Minnesota	500
Missouri	0
Nebraska	5
New Hampshire	36
North Carolina	400
Oregon	0
Pennsylvania	7,500
South Carolina	0

Additional data on in-street sign installations were collected from a variety of cities as part of a NCHRP study that is examining crash modification factors for various pedestrian safety countermeasures. In-street signs were not selected as a countermeasure because these signs were rarely reported be installed on roads with higher crash rates, such as crosswalks at multilane locations. The number of in-street sign sites for each city is shown in Table A-2. These data show that the use of this treatment varies considerable from city to city. Atlanta reported having the most crosswalk sites with a total of 300, with Washington, D.C. reporting having several 100 sites. The city of Arlington said they will only replace in-street signs 2 or 3 times. Atlanta said they used them on all types of roads. The city of Pittsburg said they take there signs down at night and the city of Cambridge said they remove the signs during the winter months. It is clear that each jurisdiction has established their own procedures for the use of these signs. Only one city, Gainesville, FL, reported using a gateway treatment and they were satisfied with the performance of the gateway in-street sign installations on multilane roads. Gainesville installed gateway in-street signs after learning of the data reported by MDOT. Subsequent information showed use of the gateway treatment in San Antonio, Texas and Palm Springs, California.

Table A-2. The number of in-street sign sites reported in 24 cities.

City	State	Number of Sites	Notes
Phoenix	AZ	None	
Scottsdale	AZ	2	"Yield to Pedestrians" in Downtown Area
Tucson	AZ	0	
La Mesa	CA	6	
Los Angeles	CA	Many	
San Francisco	CA	A few	Not sure how many remain
Santa Monica	CA	A few	
Boulder	CO	6-12	Text on in-road sign is "State Law - Yield to Pedestrians"
Washington	DC	100's	
Gainesville	FL	6	Work well, two gateway installations
St. Petersburg	FL	None	None in-road; mounted behind curb at stop bar
Atlanta	GA	300	All types of roads
Chicago	IL	39	Installed in 2011-2012, "Stop for Pedestrians"
Cambridge	MA	12	Removed during snow months
Columbia	MO	~25	
Springfield	MO	15-20	
Charlotte	NC	20-25	Most with refuge island
New York	NY	0	They're doing sign reduction; very few of these
Portland	OR	A few	
Pittsburgh	PA	20	Take them down at night
Alexandria	VA	~50	
Arlington	VA	Some	Don't replace after 2-3 replacements
Kirkland	WA	0	
Milwaukee	WI	40-50	

Chapter 1 – Configurations Influencing the Efficacy of the Gateway Treatment

Introduction

Pedestrian fatalities steadily decreased nationally from 5,801 pedestrian fatalities in 1991 to their record low of 4,108 in 2009. Pedestrian fatalities began to rise in 2010 to 4,302 and continued to rise until 2012 when there were 4,818 pedestrian fatalities. 2013 saw a slight decrease of 2% in pedestrian fatalities with a total of 4,735 (22).

Attempts to improve pedestrian safety date back to ancient Rome. The 2,000-year-old ruins of Pompeii contained raised stones for pedestrians to use to cross roads. These raised crosswalks had gaps for the wheels of the cart to pass through. This design served as a form of traffic calming because the cart driver needed to slow in order to align the cart wheels with gaps in raised crossways. Such a configuration could be thought of as a type of gateway through the crosswalk.

Bennett, Manal and Van Houten (9) placed in-street signs on each side of a multi-lane road at uncontrolled crosswalks, on the lane lines and on the center line. This novel intervention was referred to as the gateway treatment. A diagram showing the placement of signs for the gateway treatment is shown in Figure 1-1. Additional configurations for varying roadway and crosswalk characteristics are provided in the User Guide.

The 2009 version of the MUTCD (23) states that In-Street Pedestrian Crossing sign shall be placed in the roadway at the crosswalk location on the center line, on a lane line, or on a median island. It does not permit placement on a sign post at the side of the road or on top of the curb. Therefore FHWA permission to experiment is required to place them on top of the curb at the outside edges of the road but not on the curb of a refuge or median island.

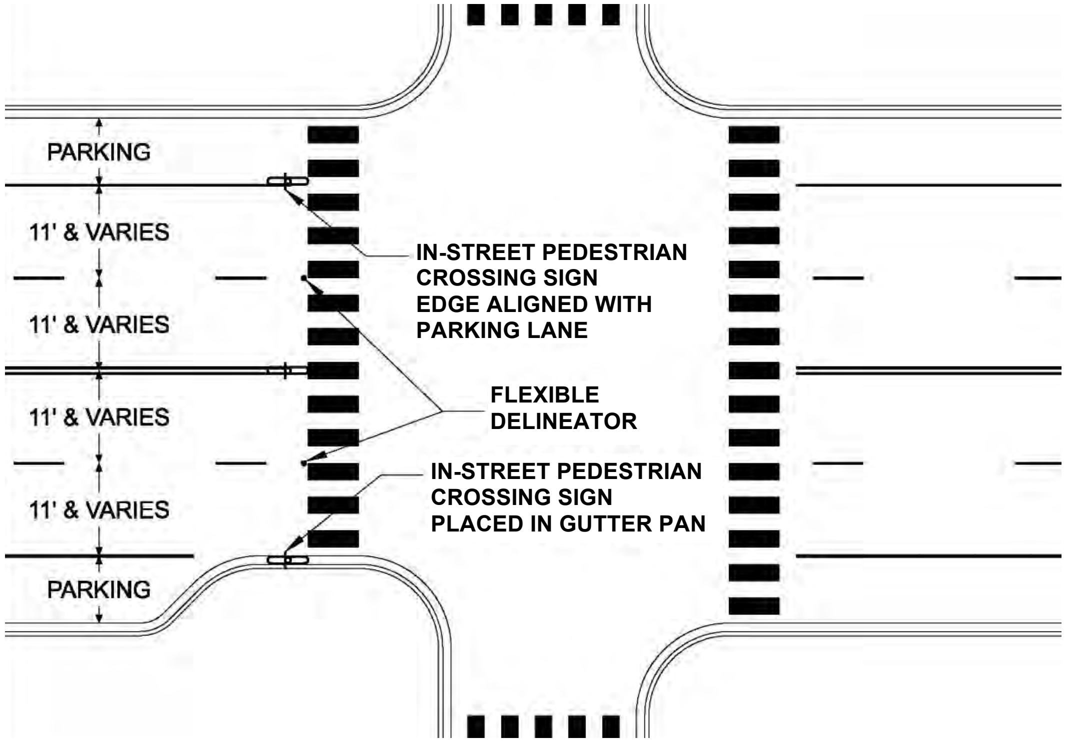

Figure 1-1: Diagram of Typical Sign Placement for Gateway Treatment

This treatment uses six signs for a four-lane road divided by a median or refuge island, and five signs for a crosswalk without a median or refuge island. The gateway treatment produced marked increases in the percentage of drivers yielding at a variety of crosswalk locations across Michigan. Yielding rates increased from a baseline average of less than 25% to 79% at one site and from 23% to 82% at another site. Prior research had demonstrated that a single in-street sign installed on the centerline was effective on two lane roads with a travel lane in each direction but were relatively ineffective on streets with two or more travel lanes in each direction (4).

The gateway treatment also produced high yielding results when used in conjunction with two proven alternative interventions, the rectangular rapid flash beacon (RRFB), and the pedestrian hybrid beacon (PHB)(9). The price of the gateway in-street sign treatment is relatively low at (approximately $200 to $300 per sign and base) and thus may be more cost effective than the RRFB (estimated cost of $20,000) or the PHB (estimated cost of $100,000). However, little is known about how often the signs may need to be replaced. The Bennett, Manal and Van Houten experiment did not test the effects of narrowing the road using the signs, the effect of the sign message, or the effects of the signs at different types of pedestrian crosswalks.

The gateway treatment is both a traffic control device as well as a geometric design element because it involves the perceived narrowing of the roadway at the crosswalk. The gateway treatment can be viewed as a traffic calming device by visually narrowing the travel path of a driver, and thereby inducing the driver to slow down when approaching the gap. Research assistants all noticed an increase in driving scanning for pedestrians when the gateway was present. Future research should directly measure driver-scanning behavior. The signs may also be more visible to drivers because of their position on the sides and center of the roadway. Pedestrians are often positioned near the location of the side signs in the gateway treatment. The extent that the sign functions as a traffic calming device was compared with the effects of the signs as a prompt for driver yielding behavior by manipulating a variety of sign features such as the presence or absence of the sign message and the narrowness of the gap.

This chapter examines the effects of the gateway with different configurations to understand how they impact driver yielding to pedestrians in crosswalks. The configurations include variations in gateway width and sign message, and partial gateway configurations. The gateway effect on reducing vehicle speed is discussed, as well.

METHODOLOGY

Dependent Variables

The number of motorists who did and did not yield to pedestrians in crosswalks was measured. Driver yielding was measured in reference to an objective dilemma zone (a location beyond which a driver can easily yield if a pedestrian enters the crosswalk). A formula used to determine whether a driver could have safely stopped at a traffic signal, was used to determine whether a driver could have stopped for a pedestrian standing with one foot in the crosswalk (24). This formula takes into account driver reaction time, safe deceleration rate, the posted speed, and the grade of the road to calculate this interval for the yellow traffic light. This formula was used to determine the distance to the dilemma zone boundary by multiplying the time (y) by the posted speed limit in feet per second:

$$y = t + \frac{v}{2a + 2Gg}$$

where t = the perception and reaction time in seconds (S); v = the speed of approaching vehicles in feet per second (the posted speed was used for approach speed); a = the deceleration rate, recommended at 10 feet/S^2; G = acceleration due to gravity (32 feet/S^2); and g = the grade of the approach. To aid observers in identifying the dilemma zone, the zone was marked by either a sprinkler flag located adjacent to the curb or with bright tape that extended from the raised concrete of the curb face into the gutter pan.

Motorists who had not passed the outer boundary of the dilemma zone when a pedestrian entered the crosswalk were scored as yielding or not yielding because they had sufficient time and space to stop safely for the pedestrian. Motorists who entered the dilemma zone before the pedestrian placed a foot in the crosswalk could be scored as yielding, but could not be scored as failing to yield because the motorist did not have adequate distance to yield based on the calculated distance. However, the signal timing formula is relatively lenient; hence, many vehicles that passed the dilemma zone could yield safely, particularly those traveling below the speed limit.

Research Design

A replication logic reversal design was used in these experiments. In replication logic reversal design, a treatment is introduced, removed, and reintroduced to isolate the effectiveness of the treatment on driver behavior independent of other environmental factors. In all preliminary studies in Chapters 1 through 4 temporary signs were installed that could be easily moved and removed by the research team. Evaluations in Chapter 5 evaluated more permanent installations that would only be removed for winter.

A trial, or staged crossing, began when a researcher demonstrated an intention to cross the street by placing one foot within the crosswalk with his or her head turned in the direction of the approaching vehicle. A research assistant recorded the results of the trial on a clipboard.

Each session consisted of 20 trials (pedestrian crossings). The percentage of drivers who yielded the right-of-way to pedestrians was calculated for each session by dividing the number of drivers that yielded the right-of-way by the number of yielding drivers and non-yielding drivers. Data were collected during daylight hours between 10:00 a.m. and 8:00 p.m. Monday through Saturday in May through November. Data were not collected when it was raining.

Scoring

Drivers in the first two travel lanes nearest the pedestrian were scored for yielding after the pedestrian had entered the crosswalk. This procedure was used because it conforms to the obligations of motorists specified in the Universal Vehicle Code and local ordinances in Kalamazoo, and Ann Arbor regarding who has the right-of-way at what time. Drivers in the second half of the roadway were scored as a separate trial if there was a pedestrian refuge or median island separating the travel way. If there was no island, drivers in the second half of the road were scored when the pedestrian approached the center of the last travel lane adjacent to the yellow centerline separating opposing lanes of traffic. Motorists were then scored using the same trial method as the crossing for the first half of the roadway.

Data Collector Training Procedure

Researchers were trained to use the operational definition of yielding behavior. They practiced recording together until they obtained inter-observer agreement (see below for a description of inter-observer agreement) of 90% or better for two consecutive sessions (a total of 40 observations). Researchers were also trained on how to use a walking wheel to measure the distance to the dilemma zone, and how to install the flags or lay the tape.

Data Collection Setup

The researchers set up the dilemma zone before beginning trials. A walking wheel was used to measure the distance from the nearest crosswalk line to the dilemma zone. During the marking process, one of the researchers served as a spotter to ensure that the person using the walking wheel was clear of traffic. Both persons wore orange vests during the marking process to make them more visible to drivers. The researchers then marked the location with the necessary flags, tape, or both.

Inter-observer Agreement

Inter-observer agreement was calculated for at least 34% of all observations in all experiments, and data were collected during each condition of each experiment in order to validate the observational data. Each event that was scored the same by both observers was counted as an agreement, and each event that was scored differently by each observer was scored as a disagreement. Inter-observer agreement was calculated by dividing the number of agreements during each session by the sum of agreements plus disagreements for that session. The result of this calculation was then converted to a percentage, as expressed by the formula below:

$$\textit{Inter-observer agreement (\%)} = \frac{\textit{Agreements per session}}{\textit{(Agreements per session+ Disagreements per session)}}$$

During sessions in which agreement data were collected, the two observers stood several meters apart at a location with an unobstructed view of the crosswalk. When more than one pedestrian crossed at a particular crosswalk, the primary observer identified the pedestrian for whom yielding behavior was to be scored by describing a distinctive feature such as whether the person was a male or female or the color of his or her clothing. They then independently recorded motorist yielding behavior and did not discuss with each other how they scored any of the trials. This procedure controlled for potential observer bias.

Inter-observer agreement on the percentage of drivers yielding to pedestrians averaged 96% over all of the studies completed in this research with a range of 88% to 100%.

Apparatus

Three types of traffic control devices (TCD)s were used in this study. The first TCD device was the R1-6 in-street sign. The second TCD was a blank sign of the exact same size as the R1-6 sign and using a similar diamond grade fluorescent yellow green background color. This was done to determine whether the language and symbols on the sign influenced the yielding rate of motorists. The third TCD was a robust flexible delineator that is designed to withstand 100 impacts at 60 mph. This device was the same color as the background of the R1-6 sign. It was examined in more vulnerable gateway treatment locations to address concerns about survivability of the intervention.

Figure 1-2 shows a R1-6 sign mounted on a curb device affixed to the roadway. Figure 1-3 shows a blank sign mounted on a removable base, and Figure 1-4 shows a flexible delineator that is screwed into a base cemented into the roadway.

Figure 1-2: R1-6 Sign mounted on a curb affixed to the roadway

Figure 1-3: A blank sign the same size as the R1-6 Sign mounted to a removable base

Figure 1-4: A flexible delineator attached to a base cemented into the pavement

EVALUATION OF THE IMPORTANCE OF GATEWAY WIDTH

The first study in this series examined the effects of gateway width on yielding behavior. The hypothesis was that the narrowing of the gateway was a factor associated with yielding behavior. This study tests this hypothesis.

Locations

The comparison of gateway widths measured the lane width from the inside edge of one R1-6 sign to the inside edge of the corresponding R1-6 sign on the other side of the travel lane. The effect of gateway width was measured at two sites at the Marshall traffic circle, one crosswalk was on the NE side of the traffic circle and the other crosswalk was on the SW side of the crosswalk. It was also measured at two trail crossings in Portage Mi. One trail crossing was on Oakland Street south of Milham Road, and second the trail crossing was on Garden Lane west of Kingston Dr. The freeway crosswalk sites were at the two uncontrolled I-94 entrance ramps from South Westnedge Avenue.

Research Design

A replication logic reversal design was employed in this study. Following multiple daily baseline measures (sessions during which no in-street sign treatment was present) the treatment was introduced at one width for multiple days. Next, the width of the gateway was changed, and observation data was collected again for multiple days. These changes were replicated by repeating measures for each of the gateway widths several times.

Table 1-1 shows yielding behavior for various gateway widths. Inspection of these data reveals that in each case, narrower configurations lead to a higher driver yielding rates than wider configurations. The gap size (the difference between the wide and narrow width) varied between 2.4 feet to 9.4 feet across sites. Although these data show that gateway width is a factor influencing yielding, it is clear that other variables also have an influence on driver yielding. This becomes apparent when one ranks sites by gateway treatment width, which reveals that some narrow locations provide better yielding rates than other sites with even narrower configurations. For example, yielding is higher at the Marshall traffic circle site than at the Oakland trail crossing and I-94 entrance ramp even though the latter two sites are considerably narrower than the Marshall traffic circle. The consistency of these data can be seen from by viewing data collected over time at the Marshall NW leg in Figure 1-5.

Table 1-1. The percentage of drivers yielding to pedestrians with a wide vs. a narrow gateway. The last column shows the change in width between the wide and narrow gateway

	Wide Configuration			Narrow Configuration			
Location	Width	Yielding		Width	Yielding		Gap Width Reduction
		Baseline	Gateway		Baseline	Gateway	
Marshall Traffic Circle Crossing SE leg	44.8 ft.	11%	15%	36.8 ft.	11%	29%	8 ft.
Marshall Traffic Circle Crossing NW leg	30.3 ft.	13%	19%	22.3 ft.	13%	48%	8 ft.
Oakland St. Trail Crossing S of Milham	17.5 ft.	2.7%	10%	11.7 ft.	2.7%	39%	5.8 ft.
Garden Ln. Trail Crossing E. of S. Westnedge	19.5 ft.	21%	67%	17.1 ft.	21%	75%	2.4 ft.
I-94 Ramp E. Bound Ramp Entrance	20.0 ft.	2%	17%	10.6 ft.	2%	31%	9.4 ft.

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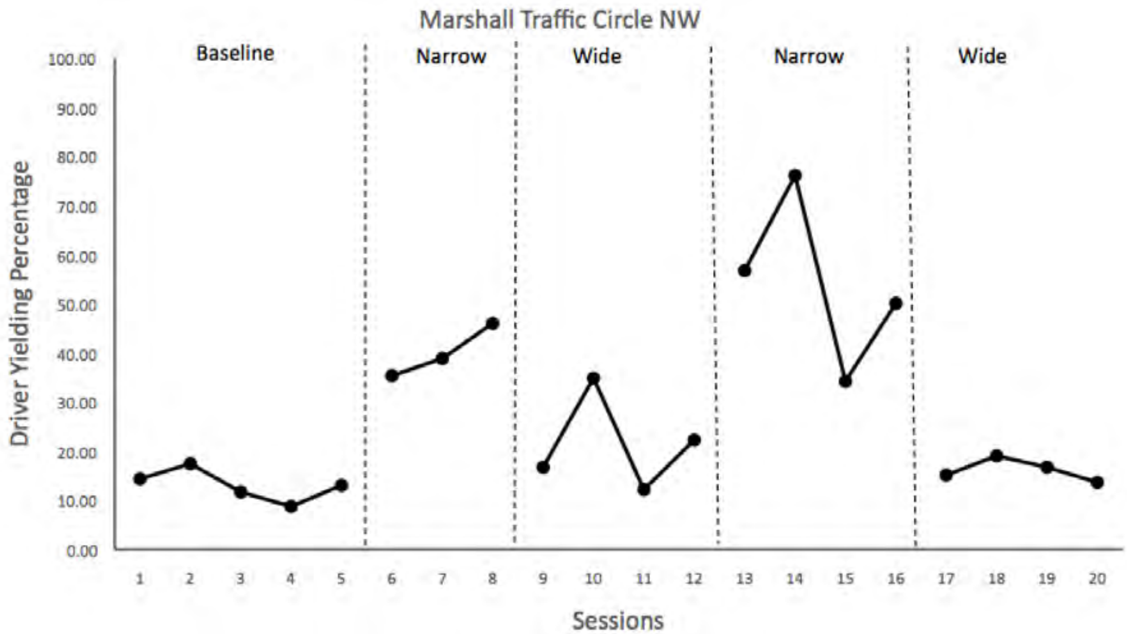


Figure 1-5. Driver yielding at the Marshall Traffic Circle NW crosswalk leg

EVALUATION OF THE IMPORTANCE OF THE SIGN MESSAGE

In order to determine whether the message on the signs in the roadway controlled driver behavior, the gateway configuration with sign blanks with the reflective background but no message were compared to the standard R1-6 sign at two different crosswalk locations. The first location was at a crosswalk at a T-intersection that traversed a multi-lane road with two travel lanes in each direction and on-street parking. The second location was at a midblock crosswalk with two travel lanes in each direction, a pedestrian refuge island and no parking.

Gateway Configurations

Two types of gateway configurations were used in this study. The first configuration was a gateway with all R1-6 in-street signs. The second type of configuration was a gateway with all blank signs of the exact same size, sign sheeting background color (diamond grade fluorescent yellow green), and shape as the R1-6 in-street sign to determine if the message on the sign influenced the yielding rate of motorists. Figure 1-6 shows a photo gateway configuration of the in-street sign with all R1-6 signs placed in the roadway. Figure 1-7 shows a gateway configuration with all blank signs. Sign placement was identical for the two configurations.

Locations

Two different sites in the city of Kalamazoo, Michigan were used in this study. The posted speed limit at both sites was 35 mph. The first crosswalk was on Rose Street at the T-intersection with Academy Street. Rose Street has four lanes with two travel lanes in each direction and on-street parking, the second site was a midblock crosswalk on Rose Street near the Kalamazoo Valley Community College Campus (KVCC) with two travel lanes in each direction and a pedestrian refuge island separating north and southbound traffic. The Annual Daily Traffic (ADT) on Rose Street was 6,820.

Figure 1-6: In-street sign showing a gateway at Rose St. at Academy St. with all R1-6 Signs

Figure 1-7: In-street sign showing a gateway at Rose St. and Academy St. with all blank signs

Research Design

Because of the robust changes produced by this treatment in the previous studies, a replication logic reversal design was employed in this study. Following multiple daily baseline measures (sessions during which no treatments were present) the treatments were evaluated in a counterbalanced order for multiple days. Data were returned to baseline and back to various treatment conditions multiple times to confirm the robust changes in driver behavior through repeated direct replications.

Results

The average percentage of drivers yielding right-of-way to pedestrians during each condition at both locations is presented in Table 1-2. At Rose Street. at Academy Street, yielding behavior during baseline condition averaged 6%. During the gateway with blanks configuration, yielding averaged 32%. During the gateway with R1-6 signs configuration, yielding averaged 80%. At the Rose Street at KVCC midblock location yielding during baseline also averaged 6%. During the gateway with blanks configuration, yielding averaged 36%. During the gateway with R1-6 signs configuration yielding averaged 78%. Figures 1-8 and 1-9 shows the average percent of drivers yielding during each session at each site. These data show that yielding behavior was relatively consistent at each site and that results did not vary when the first treatment was either the gateway with blanks configuration or the gateway with R1-6 signs configuration. The stability of the effect over multiple replications provides clear evidence that the differences in driver yielding behavior were a result of the two different treatment conditions.

Rose Street at Academy Street		Rose Street Midblock at KVCC	
Configuration	Mean Percent Yielding	Configuration	Mean Percent Yielding
Baseline	6%	Baseline	6%
Blank Signs	32%	Blank Signs	36%
R1-6 Signs	80%	R1-6 Signs	78%

Table 1-2. The mean percentage of drivers yielding to pedestrians during baseline, the blank sign gateway and the R1-6 sign gateway configurations

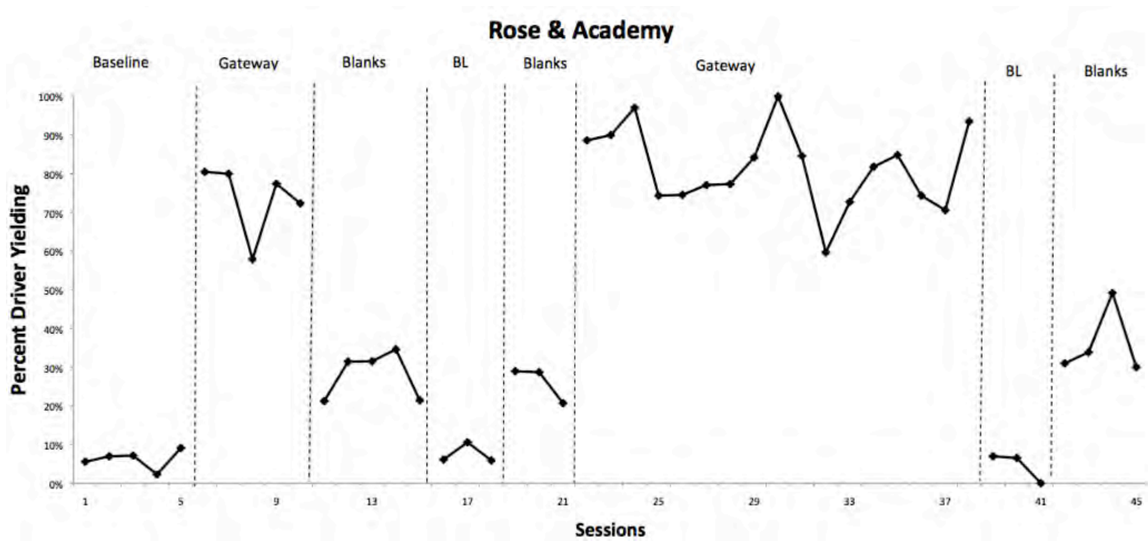


Figure 1-8. Percent of drivers yielding to pedestrians at Rose St. at Academy St.

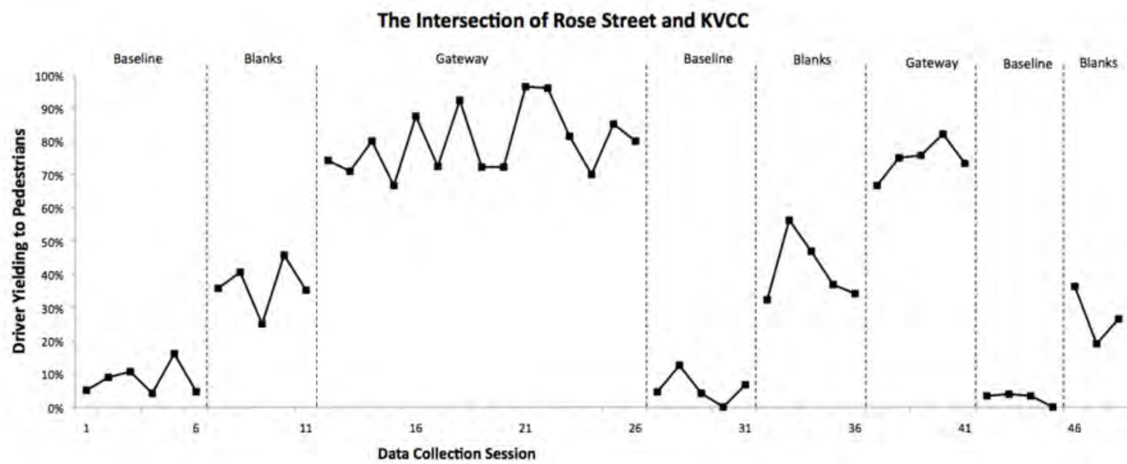


Figure 1-9. Percent of drivers yielding to pedestrians during each condition at Rose Street at KVCC.

Evaluation of Position of Signs

This study compared the full Gateway configuration with R1-6 signs only on the white lines separating travel lanes in the same direction and R1-6 signs only at the edge of the roadway at two sites.

Locations

Two different sites in the city of Kalamazoo, MI were used in this study. The posted speed limit at both sites was 35 mph. The first crosswalk was on Rose Street at the T intersection with Academy Street. Rose Street has four lanes with two lanes in each direction and on-street parking, the second site was at a crosswalk on the intersection of South Westnedge, a one-way road with two southbound lanes and on-street parking on both sides of the street, at the T-intersection with Ranney Street. The ADT on Rose Street was 6,820 and on South Westnedge it was 14,709.

Research Design

Because of the robust changes produced by this treatment in the previous study, a replication logic reversal design was again employed in this study. Following multiple daily baseline measures (sessions during which no treatments were present) the treatments were evaluated for multiple days. Data were returned to baseline and back to various treatment conditions multiple times to confirm the robust changes in driver behavior through direct replication. The treatments evaluated were 1. The full Gateway with R1-6 signs at the edges of the road and on all lane lines; 2. The placement of R1-6 signs only on the edges of the roadway; 3. The placement of the R1-6 signs only on the white lane lines separating travel lanes carrying traffic in the same direction.

Results

The results of this experiment are presented in Table 1-3. At the Rose Street at Academy location the baseline yielding was 6%, the full Gateway produced yielding of 80%, the edge signs alone condition was associated with 36% yielding and the signs only on the centerline produced 52% yielding. At the South Westnedge site yielding was 0% during baseline, 89% with the full Gateway, 10% with the edge signs alone, and 18% with signs only on the white lane lines.

Table 1-3. Mean percentage of drivers yielding to pedestrians during baseline, the full gateway, R1-6 signs only at the edges of the roadway, and R1-6 signs only on the white lane lines.

Rose St. @ Academy St.	Condition	Percent Yielding
	Baseline	6%
	Gateway with all R1-6 Signs	80%
	Centerline and Edge signs only	36%
	R1-6 Signs only on Lane Lines	52%
S. Westnedge Ave. at Ranney St.	Condition	Percent Yielding
	Baseline	0%
	Gateway with all R1-6 Signs	89%
	R1-6 Signs on Edge alone	10%
	R1-6 Sign on Lane Line alone	18%

GATEWAY EFFECT ON VEHICLE SPEED

Speed data were collected at one crosswalk in the presence and absence of the gateway treatment to determine how much drivers slowed when traversing the crosswalk.

Setting

The participants were 2,000 motorists using two southbound traffic lanes approaching the crosswalk on Rose Street at the intersection with Academy Street. Drivers were excluded if they changed lanes after their speed was read at the dilemma zone and if they parked at the southbound meters on Rose Street. It is important to note that drivers were excluded if pedestrians were attempting to enter or within the crosswalk and if motorists in northbound traffic lanes were turning or attempting to turn while a driver was in the dilemma zone. Thus these data show the effect of the gateway in the absence of pedestrians.

Method

The dependent variable was the vehicle's speed at the dilemma zone, which begins 183 feet south of the crosswalk and ends at the threshold of the crosswalk. All speeds were read using laser radar located in a vehicle parked south of the crosswalk.

Results

The results are presented in Figure 1-10. These data show drivers were accelerating during the baseline speed measures when the gateway was absent. When the gateway was introduced average speed decreased from 26.8 mph to 23.1 mph at the dilemma zone and from 28.3 mph to 18.1 mph at the crosswalk, a 10 mph drop. A single R1-6 sign located on the yellow line at the center of the road was associated with a very small reduction in speed similar to that reported in research that only used one sign (7).

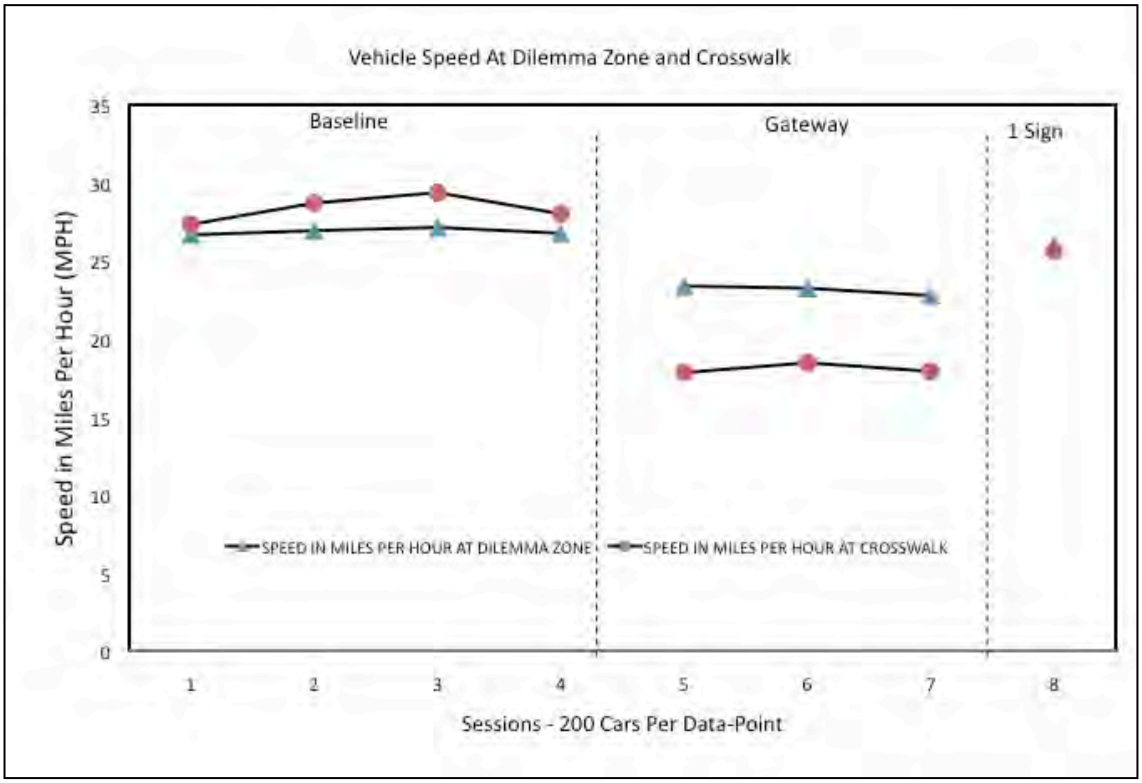


Figure 1-10. Driver speed approaching the crosswalk at the dilemma zone (blue line) and at the crosswalk (red line) during baseline and gateway condition on Rose Street at Academy.

Discussion

The purpose of this series of studies was to evaluate variables contributing to the improvement produced by the gateway treatment on driver yielding right-of-way to pedestrians at crosswalks. Although the configurations were only compared at a limited number of sites, the consistency of the results produced for each configuration introduced multiple times at each site, the obvious large changes in driver behavior, and the consistency of results between different sites suggest that these finding are robust. All of the configurations tested increased driver yielding behavior. However, no configuration matched the effectiveness of the complete gateway configuration with all R1-6 signs.

One hypothesis tested was whether the distance between the signs had an influence on the efficacy of the gateway R1-6 treatment. The analysis of gap width between signs showed that narrower configurations were more effective at each site where this variable was examined.

However, data also showed that sign placement had an effect on sign efficacy. Placing signs on the white lane line positions alone produced better driver yielding behavior than signs placed only on the roadway edge at all sites and the full gateway produced the highest level of driver yielding behavior.

Another hypothesis tested was whether the content of the signs influenced driver yielding behavior. The blanks configuration was significantly less effective than the configuration with the sign message present.

Speed data suggest that the gateway treatment has a marked effect on vehicle speeds approaching the crosswalk, and that drivers began slowing at the dilemma zone when they saw the gateway ahead at the crosswalk. These data were collected because research assistants frequently observed drivers slowing as they approached the crosswalk. Not only was the magnitude of the reduction clearly visible, but it also reduced vehicle speed below the speed associated with fatal crashes (25). Speed reductions can reduce both the probability of a pedestrian crash by giving drivers more time to react, and reducing the tunnel vision associated with higher vehicle speeds. Reduced speed can also decrease the severity of injuries should a crash occur.

In order to determine whether the Gateway increased the percentage of hard braking data were recorded on hard breaking at two sites in Ann Arbor, MI: Nixon Rd. at Bluett Rd., and S. Division St. at E. Jefferson, St. At the Nixon Rd. crosswalks 758 vehicles that slowed at the crosswalk were observed and no instances of hard braking were observed. At the S. Division crosswalk 912 vehicles that slowed were observed and only one instance of hard braking was observed. These data were collected several weeks after the permanent installations.

CHAPTER 2 – EVALUATION OF CONFIGURATIONS THAT IMPROVE SURVIVAL OF THE GATEWAY TREATMENT

INTRODUCTION

Although the gateway R1-6 treatment in some applications has proven to be as effective at increasing yielding right-of-way to pedestrians as more expensive treatments like the RRFB and PHB, it is more easily damaged than treatments mounted on a mast arm or on the side of the road. The PHB has been shown to increase the percentage of drivers yielding to pedestrians in Michigan to between from 61% and 95% and the RRFB has been shown to increase yielding in Michigan to between 55% and 89% (12). There are several ways to reduce the vulnerability of the gateway treatment. One way to improve sign survival is to install the signs at the roadway edge position of the gateway out of the travel way in the gutter pan. Gutter pan installation is less likely to be hit but has several potential drawbacks. First, it could present drainage issues at some locations when debris accumulates around the sign. Second, gutter pan placement could be a problem for street sweepers. Third, there may not be a gutter pan and the entire lane may be needed for larger vehicles. Fourth, narrow bike lanes may preclude gutter pan placement because the sign would be too close to riders.

One alternative to gutter pan placement is placement on top of the curb. This placement would be less vulnerable to collision and does not have any of the potential drawbacks of gutter pan sign placement and could be used at edges at the side of the road and at the edges of refuge islands or a median island. Signs placed on top of the curb as part of a gateway treatment look very similar to signs placed in the gutter pan to approaching drivers and may produce similar effects. However, curb top placement is only permitted on median and refuge islands but not at the edge of the road. Placement at the right edge of the road currently requires permission to experiment from the Federal Highway Administration (FHWA). Therefore, permission to experiment was obtained from FHWA for this study prior to placing R1-6 signs on top of the curb at the right edges of the road.

Another way to increase the survival of in-street signs placed in more vulnerable locations on while lines dividing lanes carrying traffic in the same direction is the use of a flexible robust delineator at these gateway positions rather than a R1-6 sign. These delineators have been documented to take large number of hits at speeds greatly in excess of those expected at most crosswalk locations and hence should be expected to have a relatively long life. At sites with two lanes in each direction and a pedestrian refuge island separating opposing traffic, edge signs on both sides of the gateway could be installed out of the travel way on top of the curb on both sides of the road, on top of the edge of the refuge island, and a flexible delineator post can be installed on the white lines dividing travel lanes. On roads without a pedestrian refuge island, a R1-6 sign would be required on the yellow centerline. Signs placed on a curb type base may show the best survival in this condition.

The purpose of this series of studies is to compare the effects of gutter pan versus curb top placement and R1-6 sign versus robust delineator placement on white lane lines on driver yielding right-of-way to pedestrians. In Experiment 1, gutter pan versus curb top placement was compared at four sites. In Experiment 2, the use of the R1-6 sign on the white lane line was compared with the use of the robust delineator on the lane line.

EVALUATION OF GUTTER PAN VERSUS CURB TOP PLACEMENT

In order to determine the difference in yielding behavior between placement of R1-6 signs in the gutter pan and on top of curb, the gateway configuration edge signs placed in the gutter pan were directly compared with the edge signs placed on top of the curb at four locations.

Gateway Configurations

Two types of gateway configurations were used in this study. The first configuration was a gateway with all R1-6 edge signs in the gutter pan. The second type of configuration was a gateway with all R1-6 signs on top of the curb on the side of the road or if present the side of the median island. Figure 2-1 shows a gateway configuration with the edge signs on the curb.

Figure 2-1. Gateway configuration with the edge sign on the curb at a crosswalk on East Huron Street.

Locations

Four different crosswalks, three in the city of Ann Arbor, MI and one in the city of Kalamazoo, Michigan were studied in this experiment. The first crosswalk was on East Huron between N. Thayer St. and N. Ingalls St. East Huron at this location has two travel lanes in each direction separated by a pedestrian refuge island and a speed limit of 30 mph. The second crosswalk was a midblock location on South 7^{th} Street north of Pioneer School Drive and had a posted speed of 35 mph. This street has two lanes and a bike lane in one direction and one lane and a bike lane in the second direction with a median island separating the two directions of travel. The third crosswalk was on Nixon Rd. at Bluett Rd. Nixon Rd. has two lanes in one direction and one lane in the other direction and a posted speed limit of 30 mph. At all of the Ann Arbor crosswalks, the R1-6a sign was used with a stop sign symbol in place of the yield sign symbol because Ann Arbor had a stop rather than a yield ordinance. The fourth crosswalk was on Rose Street at the T-intersection with Academy Street in Kalamazoo. Rose Street has four lanes with two lanes in each direction, on-street parking, a speed limit of 35 mph and an ADT of 6,820.

Experimental Design

A replication logic reversal design was employed in this study. Following multiple daily baseline measures (sessions during which no treatments were present) the edge signs were first installed in the gutter pan and evaluated, then placed on top of the curb and evaluated. After a return to the baseline (no gateway) condition the signs were again introduced and evaluated in a counterbalanced order for multiple days. Data were returned to baseline and back to various treatment conditions multiple times to confirm the changes in driver behavior through repeated direct replications.

Results

The average percentage of drivers yielding right-of-way to pedestrians during each condition at both locations is presented in Table 2-1. At the midblock location on E. Huron Street, yielding behavior averaged 62% during the baseline condition, 97% during the gutter pan placement condition, and 92% during the curb top placement condition. At the midblock location on 7th Street, driver yielding averaged 15% during the baseline condition, 70% during the gutter pan placement condition, and 54% during the curb top placement condition. At the Nixon Rd. and Bluett Rd. Site yielding averaged 40% during baseline, 93% during the gutter pan placement condition, and 86% during the curb top condition. At the Rose St. and Academy St. site, yielding averaged 6% during baseline, 82% during the gutter pan placement condition, and 72% during the curb top placement condition. Average performance across all four sites was 31% during baseline, 86% during the gutter pan placement condition, and 76% during the curb top placement condition. Although yielding was 10% lower during the curb top placement condition, it was still markedly higher than baseline. Figures 2-2, 2-3, 2-4, and 2-5 show the average percent of drivers yielding during each session at each crosswalk. These data show that yielding behavior was relatively consistent at each site and that results did not vary when gutter pan placement was the first treatment or curb top placement condition was introduced first. The stability of the effect over multiple replications provides clear evidence that the differences in driver yielding behavior were a result of the two different treatment conditions.

Table 2-1. The percent of drivers yielding to pedestrians during the baseline, gutter pan placement and curb to placement conditions using R1-6 signs on a temporary basis.

Location	Baseline	Gutter Pan Placement	Curb Top Placement
E. Huron Midblock	62%	97%	92%
Midblock 7th Street	15%	70%	54%
Nixon Rd. at Bluett Rd	40%	93%	86%
Rose St. at Academy St.	6%	82%	72%
Mean	**31%**	**86%**	**76%**

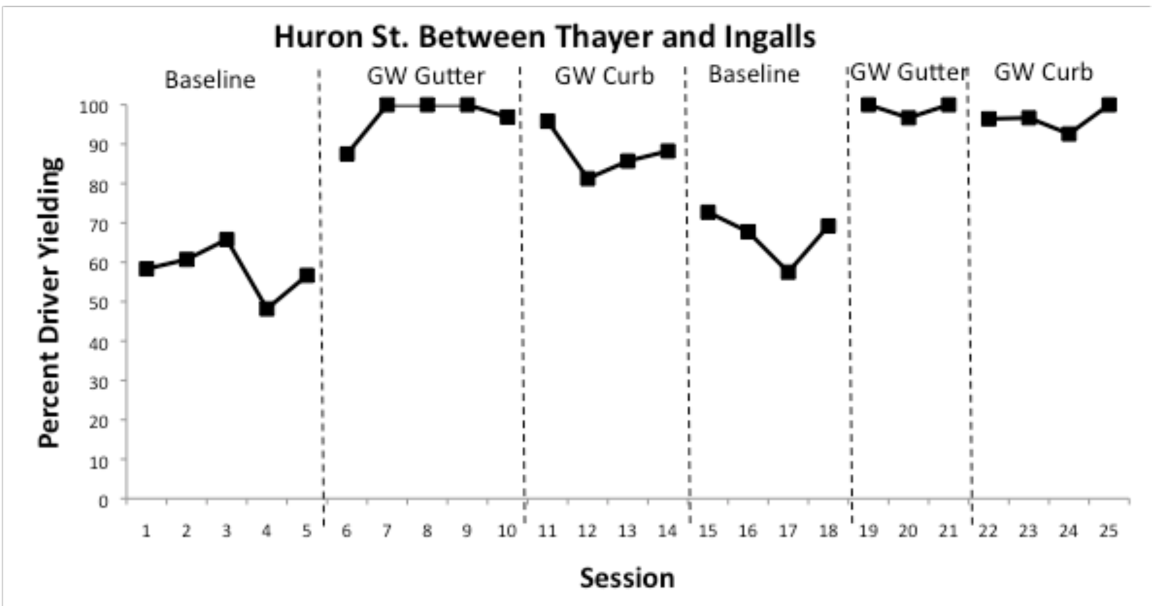


Figure 2-2. Percent of drivers yielding during each condition of the experiment

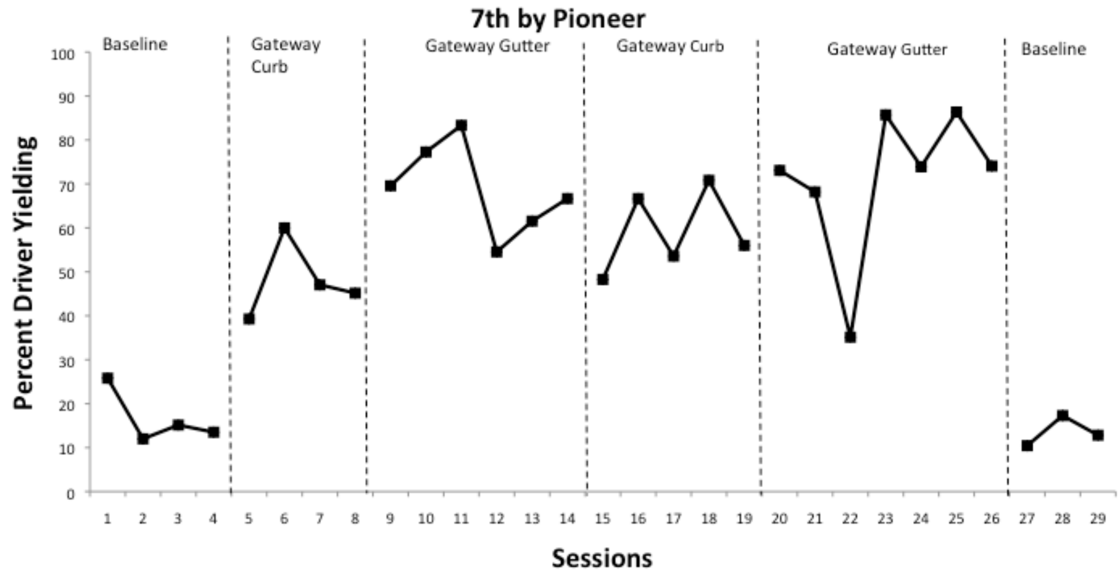


Figure 2-3. Percent of drivers yielding during each condition of the experiment

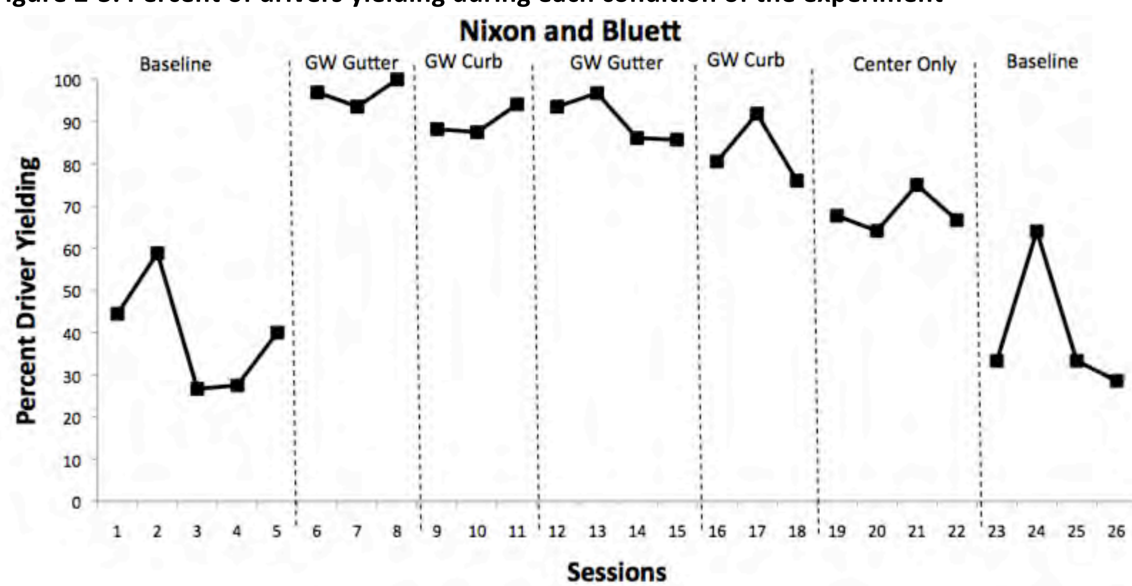


Figure 2-4. Percent of drivers yielding during each condition of the experiment

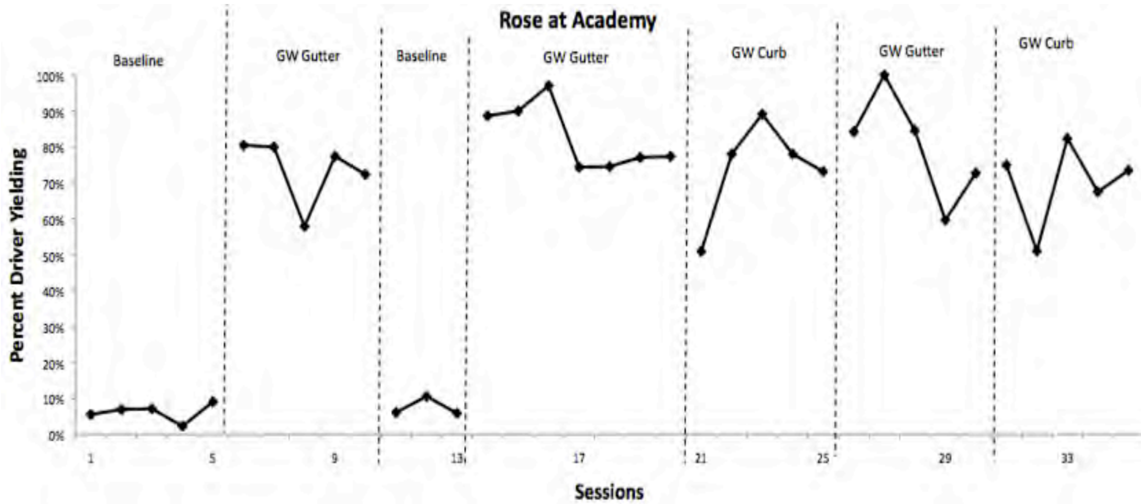


Figure 2-5. The percent of drivers yielding during condition of the experiment.

EVALUATION OF ROBUST DELINEATOR ON THE WHITE LANE LINE

One of the most vulnerable positions in a gateway treatment is the white lane line on multilane roads. The use of a robust delineator offers several advantages. First, it is narrower than a R1-6 sign. Second, it can survive significantly more hits at higher speeds. The delineator selected for testing in this study had been tested and found to withstand 100 hits at speeds of 60 mph. The purpose of this study is to determine how much the effectiveness of the gateway declines when a yellow green delineator is substituted for the R1-6 signs in the white lane line position.

Gateway Configurations

Two types of gateway configurations were used in this study. The first configuration was a gateway with three R1-6 signs in each direction (two edge signs and one on the center white line). The second type of configuration was a gateway with two edge R1-6 signs and a delineator on the white lane line in each direction. Figure 2-6 shows a photo of a gateway configuration with a delineator on the white lane lines.

Figure 2-6. Gateway treatment with delineators placed on white lane lines

Locations

Three crosswalk locations in the city of Kalamazoo, Michigan were used in this study. All three crosswalks had multiple travel lanes in the same direction of travel. The first location was on Rose Street at the T-intersection with Academy Street. Rose Street has four lanes with two lanes in each direction and on-street parking, the second site was a midblock crosswalk on Rose Street near KVCC with two lanes in each direction and a pedestrian refuge island separating north and southbound traffic, and the third crosswalk was on a one-way road with two southbound lanes and on-street parking on both sides of the street on south Westnedge Avenue at the T-intersection with Ranney Street. The ADT on Rose Street was 6,820 and on South Westnedge it was 14,709.

Experimental Design

A replication logic reversal design was employed in this study. Following multiple daily baseline measures, the treatments were evaluated in a counterbalanced order for multiple days. Data were returned to baseline and back to various treatment conditions multiple times to confirm the changes in driver behavior through repeated direct replications.

Results

The average percentage of drivers yielding right-of-way to pedestrians during each condition is show in Table 2-2. Driver yielding right-of-way to pedestrians averaged 5% across the three sites during baseline. The complete gateway with all R1-6 signs increased yielding to 82% while the gateway with the delineator was associated with 60% increase in yielding. Figures 2-7, 2-8 and

2-9 show that the individual level of yielding was very similar for each condition during each replication.

Table 2-2. The percentage of drivers yielding to pedestrians at each crosswalk during the baseline, the gateway with all R1-6 signs, and the gateway with delineator condition.

Location	Baseline	Gateway with all R1-6 Signs	Gateway with Delineator
Rose Street at Academy Street	7%	79%	60%
Rose Street at KVCC	7%	77%	60%
South Westnedge Avenue at Ranney Street	0%	89%	59%
Mean	5%	82%	60%

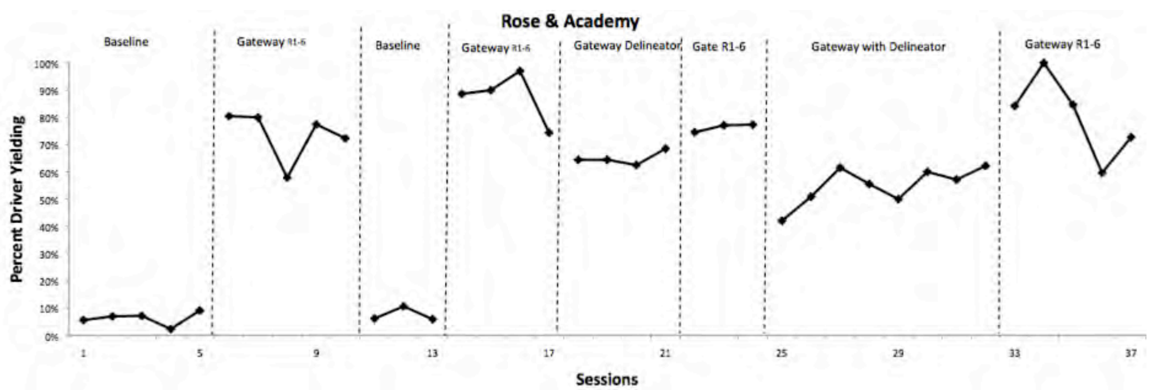


Figure 2-7. The percentage of drivers yielding to pedestrians at Rose and Academy during baseline, the R1-6 gateway conditions, and the gateway with delineator condition.

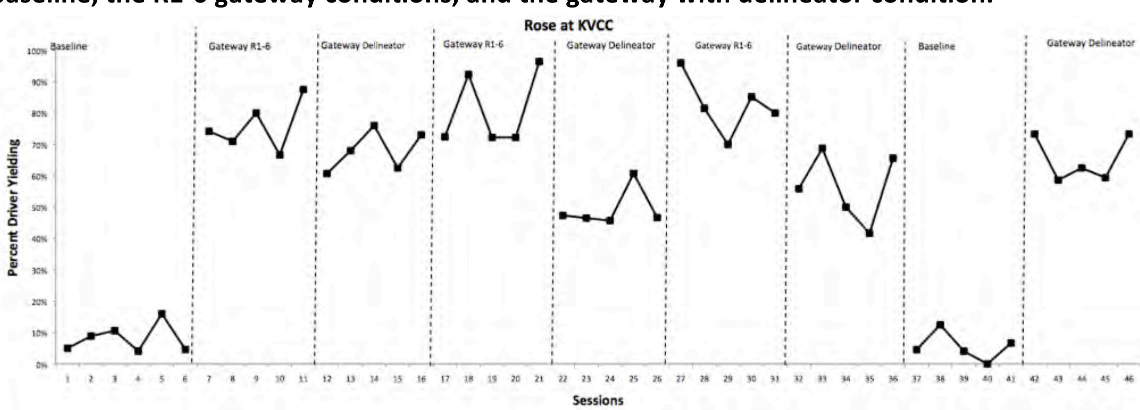


Figure 2-8. The percentage of drivers yielding to pedestrians at Rose at KVCC location during baseline, the R1-6 gateway conditions, and the gateway with delineator condition.

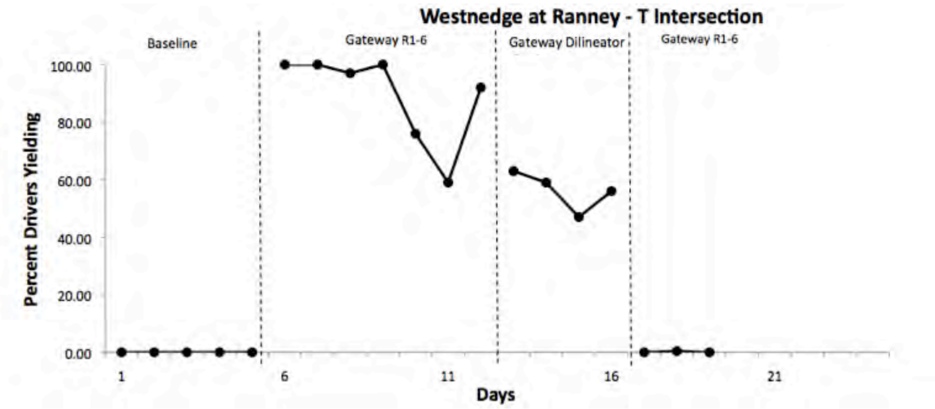


Figure 2-9. The percentage of drivers yielding to pedestrians at Westnedge and Raney during baseline the R1-6 gateway conditions and the gateway with delineator condition.

Discussion

The purpose of this series of studies was to evaluate whether gateway configurations with a potentially higher likelihood of survival could yield similar results as those produced by the full R1-6 gateway configuration. The results of the first study showed the curb top placement of the edge signs could increase driver's yielding right-of-way to pedestrians to levels almost as good as those produced by gutter pan placement. Although signs placed in the gutter pan area should not be struck very often, they could present problems for drainage, street sweepers, and at locations with narrow bicycle lanes. Placement on top of the curb would not share these limitations. It is also the case that signs placed on top of the curb should also receive less intentional strikes then signs placed in the gutter pan. Another advantage of curb top placement is that the sign bases could remain in place during the winter plowing season in northern climates. However, it is not clear whether the signs themselves could stand up to the snow load from plowing.

The second study examined whether replacing the R1-6 signs installed on the white lane line on multilane roads with a flexible delineator could produce a similar percentage of drivers yielding right-of-way to pedestrians. The results of this study showed that a gateway with delineators produced much better yielding than baseline but 22% fewer drivers yielded right-of-way to pedestrians during this condition than during the R1-6 sign on white lane lines condition. One advantage offered by the delineator is that they can withstand a large number of strikes. Another advantage is that they can be easily screwed out before the start of the plowing season in northern climates, and can be replaced in a matter of minutes.

CHAPTER 3 – EVALUATION OF THE GATEWAY TREATMENT IN VARIOUS CROSSWALK APPLICATIONS

This chapter evaluates the use of the gateway treatment in a variety of crosswalk applications, including traffic circles, roundabouts, freeway entrance ramps, and trail crossings. These applications revealed strengths and weaknesses of the gateway treatment location and helped determine where they may be most effectively deployed. Also, the chapter evaluates the use of a gateway in conjunction with a RRFB. The final study in this chapter examines whether placing the gateway at one crosswalk at an intersection would have an effect of yielding at the untreated leg.

TRAFFIC CIRCLE INSTALLATIONS

Locations

A gateway was installed at two crosswalks at a traffic circle in Marshall, Michigan. Both gateways were installed between the painted area adjacent to the center island of the traffic circle and the gutter pan on the outside of the circle. One crosswalk location had a wide configuration with a single lane roadway width of 36.8 feet between the painted area and the outer curb. The second crosswalk location had a narrow configuration with a single lane road width of 22.3 feet between the painted area and the outer curb. The left frame of Figure 3-1 shows the wide configuration crosswalk and the right frame shows the narrow configuration crosswalk.

Results

The data, as shown in Figure 3-2, illustrates that yielding increased more at the site with the narrow configuration.

Figure 3-1. Left: wide gateway. Right: narrow gateway.

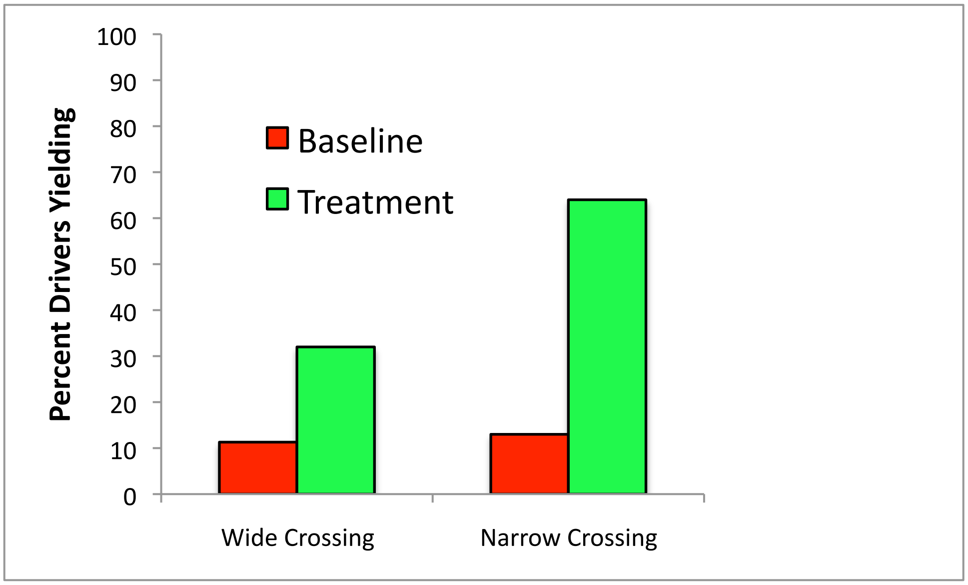


Figure 3-2. Driver yielding at the two crosswalks at a traffic circle in Marshall, Michigan.

Discussion

Gateway treatments at traffic circles improved driver yielding. However, narrowing the gateway gap resulted in a higher yielding percentage. Data reported in Chapter 1 also compared wide and narrow gateway configurations at both of these sites and found better yielding with the narrower configuration.

ROUNDABOUT INSTALLATIONS

Locations

The gateway configuration was examined at two single-lane roundabout locations in Benton Harbor, Michigan. Each roundabout has splitter islands at each entry and exit point that served as pedestrian refuge islands. There is also an island in the middle of each roundabout with low growing foliage. Yielding was only measured at the four crosswalks on East Main Street. The posted speed limit was 35 mph at both roundabouts. There was little pedestrian traffic at each site, but a large amount of vehicle traffic. Figure 3-3 shows the gateway configuration at one crosswalk leg of the roundabout at the East Main Street. Note that all signs were placed in or adjacent to the gutter pan. It should be noted that there was a lot of truck traffic at this site.

Research Design

A multiple baseline design was employed in this experiment. After data were collected during the baseline condition at both sites, one site received the gateway in-street sign treatment while the second location remained in the baseline (untreated) condition. After a convincing increase was noted at the first site, the gateway treatment was added at the second location. Some of the yielding data was separately coded for driver entering and exiting the crosswalk.

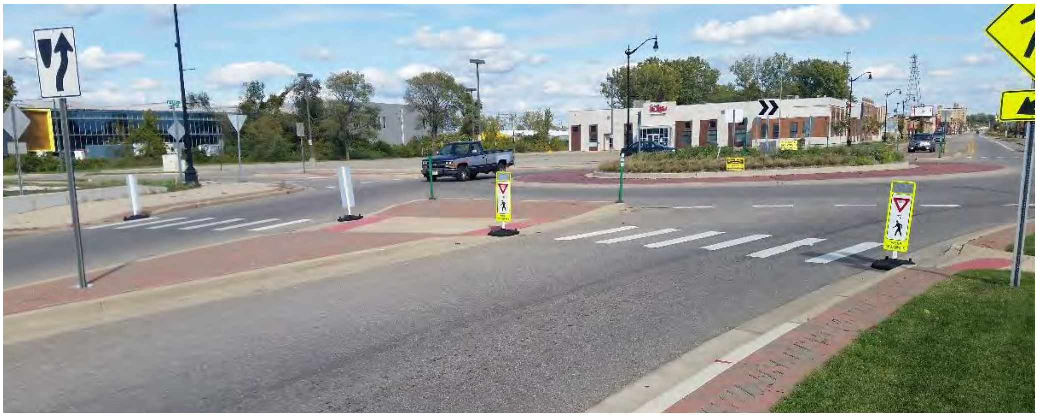


Figure 3-3. Gateway configuration at one of the roundabout locations.

Results

Figure 3-4 shows the percentage of drivers yielding right-of-way to pedestrians at each location. Baseline driver yielding behavior at the East Main St. at Riverview Dr. and East Main St. at 5th St. roundabouts averaged 9% and 19% respectively. The introduction of the gateway at the East Main Street and Riverview Dr. site increased yielding to 43%. The introduction of the gateway at the East St. and 5th site increased yielding to 45%.

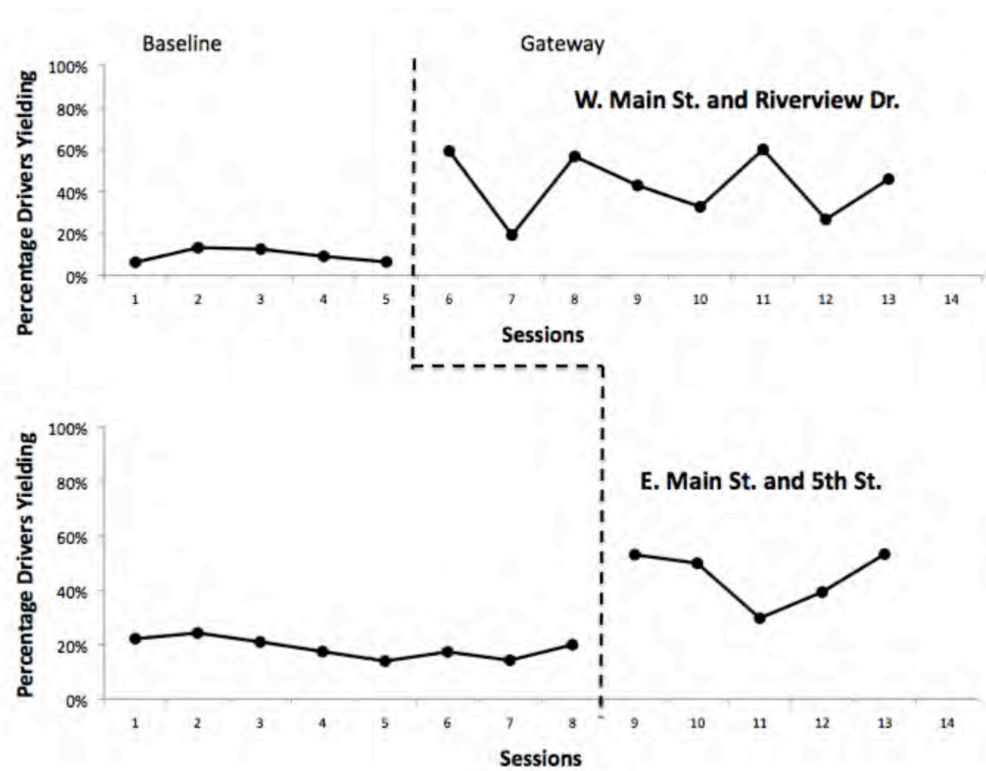


Figure 3-4. The percentage of drivers yielding right-of-way during the baseline and gateway treatments at the two roundabout locations.

Data for Drivers Entering and Exiting Roundabouts

Because the frequency of driver yielding right-of-way to pedestrians seemed higher for drivers entering the roundabout than exiting the roundabout, data collectors were instructed to separately measure the yielding behavior of drivers entering and exiting the roundabout. Figure 3-5 shows the ratio of drivers yielding right-of-way to pedestrians when entering the roundabout compared to yielding when exiting the roundabout. Drivers were almost twice as likely to yield right-of-way to a pedestrian when entering as compared to exiting the roundabout at these two sites.

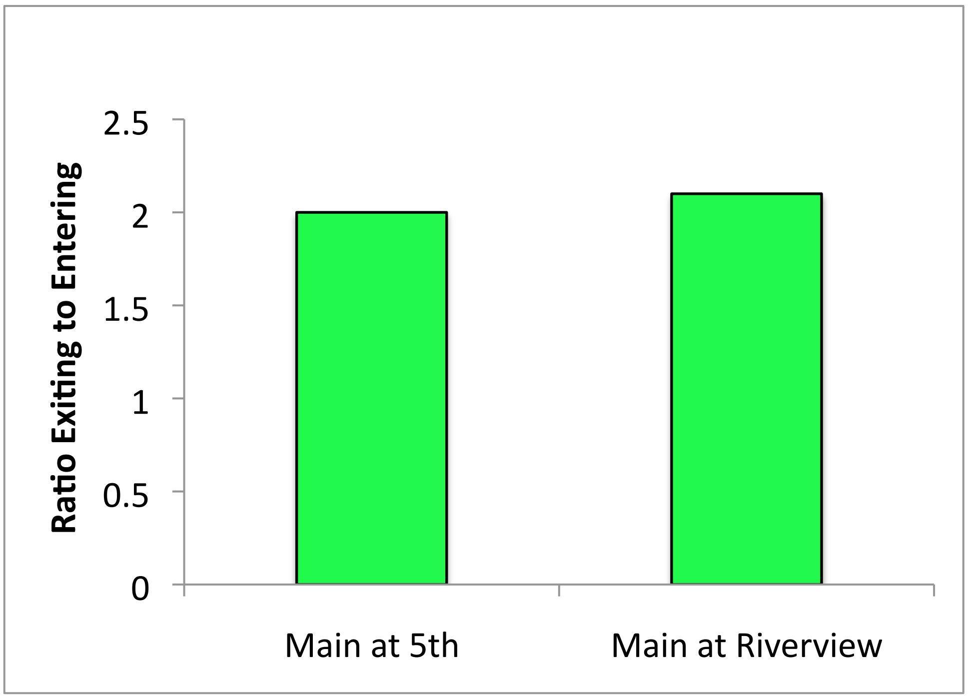


Figure 3-5. Ratio of drivers yielding to pedestrians upon entering and exiting the roundabout during the baseline condition.

Discussion

Drivers were less likely to yield right-of-way to pedestrians in crosswalks when exiting the roundabout than when entering it. Although the treatment increased yielding when drivers were entering or exiting, this relationship continued to hold with drivers much less likely to yield when exiting than entering. Although the effects at roundabouts were modest, they would make it easier to cross. Because other data show that the combination of the gateway with a RRFB leads to very high levels of yielding, this treatment should be considered at roundabouts with an RRFB location with relatively poor driver yielding behavior.

FREEWAY ENTRANCE RAMP INSTALLATIONS

Another possible application for the gateway treatment is at freeway entrance ramp locations. Pedestrians crossing entrance ramps either approach the crosswalk facing approaching traffic or with approaching traffic at their back. Crash risk should be higher for pedestrians approaching the crosswalk with traffic approaching from behind.

Locations
The gateway configuration was examined at the south and north entrance ramps to I-94 on South Westnedge Avenue. Both ramps have a long dedicated approach lane to the ramp entrance. Figure 3-6 shows the approach to the north ramp. The left frame of Figure 3-7 shows a photograph of the wide gateway configuration at the north entrance ramp and the right frame shows a photograph of the narrow gateway configuration. The wide configuration consisted of two R1-6 signs installed in the gutter pan, while the narrow configuration added two flexible delineator posts on the lane lines.

Figure 3-6. Photograph of the sidewalk approaching the north entrance to Interstate I-94 at Westnedge Avenue.

Figure 3-7. The photo on the left shows the wide configuration of the gateway and the photo on the right shows the narrow configuration with added flexible delineator posts on the lane lines.

Research Design

A multiple baseline design was employed in this experiment. After data were collected during the baseline condition at both sites, the north entrance ramp received the wide gateway in-street sign treatment while the south entrance ramp location remained in the baseline (untreated) condition. After a convincing increase was noted at the first site the wide gateway treatment was added at the second location. Next the narrow gateway configuration was introduced at the north ramp.

Results

The results of this experiment are shown in Figure 3-8. Driver yielding during the baseline condition was negligible at both entrance ramps (1% at the south ramp and 2% at the north ramp). During the wide gateway condition yielding increased to 17% at the south ramp and to 13% at the north ramp. When the narrow gateway condition was introduced at the north ramp, yielding increased to 31%, until a truck struck one of the temporary delineators destroying it. Given the limited number of temporary delineators available, the WMU team decided to end data collection at the ramp exit sites.

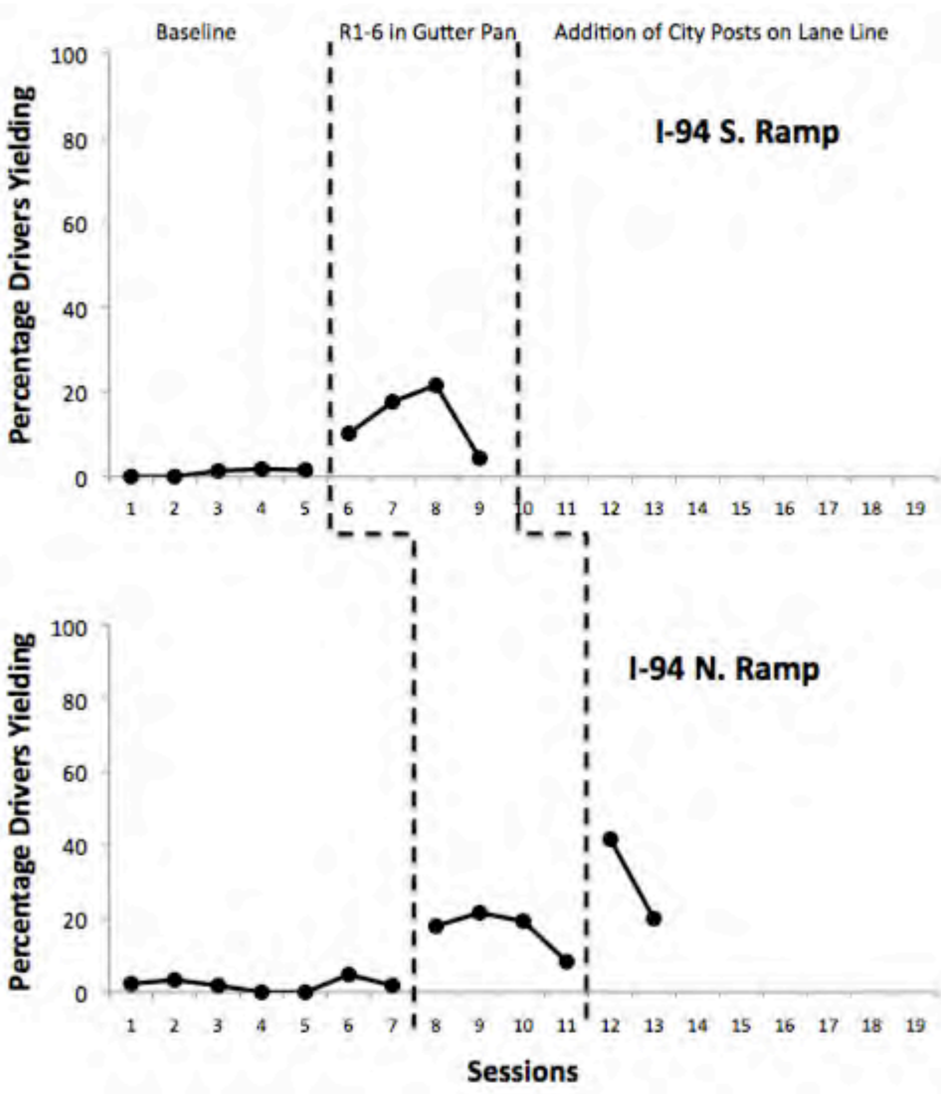


Figure 3-8. Percentage of drivers yielding to pedestrians at the south and north entrance ramp to I-94 during each condition of the experiment

Discussion

Although the wide gateway placed in the gutter pan at an entrance ramp produced some increase in driver yielding to pedestrians in the crosswalks, it was not sufficient to recommend the gateway for this application. Although there was an increase in yielding produced by the narrow configuration with added delineators, the levels obtained were still far lower than the effects obtained at midblock locations and at uncontrolled crosswalks at intersections with a stop-controlled minor cross street. Heavy truck traffic at freeway entrance ramps also make it unlikely that a narrow configuration would survive at this type of location. The only installation that would likely survive for long-term use would be curb top placement and it is unlikely that they would produce meaningful increases in yielding at this type of site.

One reason why the gateway was so ineffective at this type of site is the tendency for drivers to want to increase speed to match traffic on the freeway at the top of the ramp. Once a driver is the process of acceleration they become less likely to make the effort to switch their foot from the accelerator pedal to the brake. This phenomenon is also likely at work at exits to roundabouts where drivers are in the process of accelerating.

TRAIL CROSSING INSTALLATIONS

Locations

The gateway treatment was examined at two trail crossing locations in Portage, Michigan. The first site was a midblock trail crossing on Oakland Street just south of Milham Road. This trail crossing has a refuge island. There is also a constant flashing yellow beacon in advance of this site and a push button activated flashing yellow beacon at the crosswalk location. The second site was a trail crossing on Garden Lane on the Celery Creek trail. The wide gateway configuration at Oakland Street is shown in Figure 3-9. The wide gateway configuration at Garden Lane is shown in the lower frame of Figure 3-10.

Figure 3-9. Wide gateway configuration on Oakland Street

Figure 3-10. Wide gateway configuration at the trail crossing on Garden Lane.

Research Design
A reversal design was employed at both sites. In a reversal design a treatment is introduced, removed, and reintroduced in order to replicate the effect of the treatment on driver's behavior.

Results
Table 3-1 shows the average percentage of drivers yielding to pedestrians during each condition at both sites. The percentage of drivers yielding right-of-way to pedestrians during baseline was 3% at the Oakland Street trail crossing and 21% at the Garden Lane trail crossing. At both crossings the narrow R1-6 gateway produced the highest level of yielding behavior with 39% yielding at the Oakland Street location and 75% yielding at the Garden Lane location. The wide treatment condition with delineators placed into the position used for the R1-6 signs for the narrow condition was associated with 18% yielding at the Oakland Street location and 72% yielding at the Garden lane location.

Because there was a pedestrian activated flashing yellow beacon at the Oakland site it was tested alone and with the wide and narrow R1-6 gateway conditions. The pedestrian beacon alone was associated with 2% yielding, the wide gateway configuration yielding increased to 23% and the beacon with the narrow configuration was associated with 57% yielding. The lower frame of Figure 3-11 shows yielding at the Oakland Street location and the upper frame of Figure 3-11 shows yielding at the Garden Lane location.

Table 3-1. The percentage of drivers yielding right-of-way to pedestrians during each condition at the two trail crossings.

Oakland Street Trail Crossing		Garden Lane Trail Crossing	
Condition	Percent Yielding	Condition	Percent Yielding
Baseline	3%	Baseline	21%
R1-6 gateway Wide	10%	R1-6 gateway Wide	67%
R1-6 gateway Narrow	39%	R1-6 gateway Narrow	75%
Robust Delineator Alone	5%	Robust Delineator Alone	61%
R1-6 gateway Wide + RD Narrow	18%	R1-6 gateway Wide + RD Narrow	72%
Baseline + Beacon	2%	Baseline + Beacon	NA
R1-6 gateway Narrow + Beacon	57%	R1-6 gateway Narrow + Beacon	NA
R1-6 gateway Wide + Beacon	23%	R1-6 gateway Wide + Beacon	NA

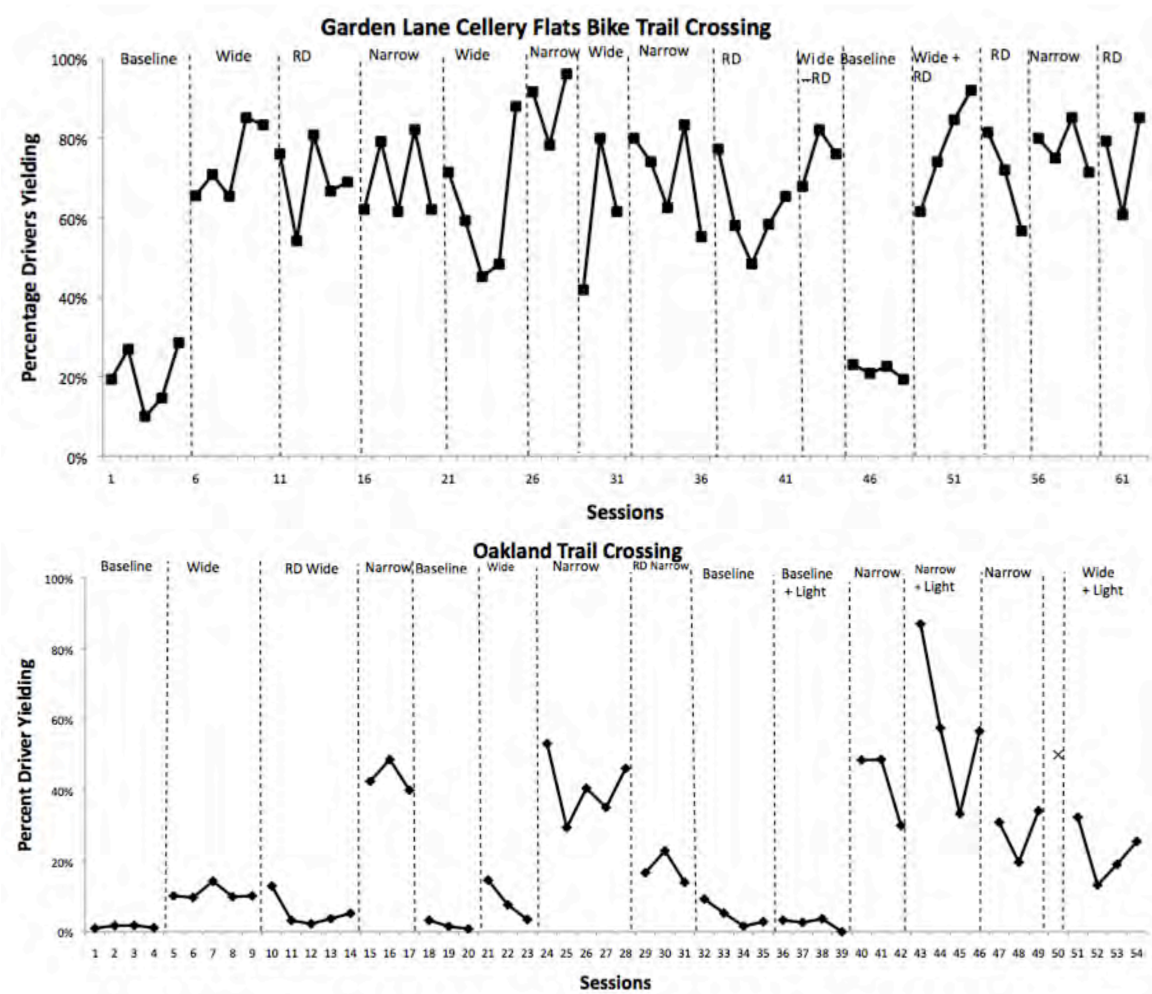


Figure 3-11. Percentage of drivers yielding to pedestrians during each condition at the two trail crossings during each treatment condition.

Discussion

The gateway was highly effective at one of the trail crossings but only moderately effective at the second crossing, which had a higher ADT (nearly 17,000) and speed (35 mph). The crosswalk on Oakland Street had a traffic signal north of the midblock trail crossing. It was noticed that vehicles accelerating from a fresh green signal seemed to be less likely to yield as were drivers approaching a green signal from the opposite direction. Observers also thought many vehicles were traveling over the speed limit at this site. This site also had a large number of platooned vehicles due to the close proximity of the traffic signals which released the vehicles when the light turned green. This may be a factor worthy of further study.

Installation at an RRFB Location

An RRFB is another way to increase motorist yielding right-of-way to pedestrians at crosswalks. Another possible application for the gateway treatment is at RRFB sites (8, 11, 26). Previous research has documented the efficacy of the R1-6 sign used alone on the yellow line or in a gateway configuration to increase yielding at crosswalks controlled by an RRFB or PHB at locations where the RRFB or PHB produced less yielding than reported in national studies (9).

Locations

The gateway configuration was examined with a RRFB at a midblock location at a small park on Monroe Street East of Chestnut Street in Allegan, Michigan. The crossing has a pedestrian refuge island. The edge signs adjacent to the refuge island were placed in the gutter pan and the signs adjacent to the curb were placed on the white lane lines, as shown in Figure 3-12.

Figure 3-12. RRFB location in Allegan, Michigan.

Research Design

A multiple element design was employed in this experiment. During the baseline phase two data sets were collected each day, one without and one with the RRFB activated. Subsequently, the gateway devices were installed and data collected with the RRFB activated and not activated.

Results

The results of this experiment are shown in Table 3-2. Driver yielding during the baseline averaged 18% when the device was not activated and 65% when the RRFB was activated. This result is somewhat lower than that found in national studies (8, 11, 25). After the gateway was installed, yielding when the RRFB was not activated increased to 82% and averaged 96.5% when the RRFB was activated. It is interesting to note that the complete gateway alone in September was more effective than the RRFB before the gateway was introduced. As in previous studies the gateway produced a marked increase in the efficacy of the RRFB. One of the edge signs on the lane line was damaged before October 2015 and November 2015 data were collected. This produced a drop in yielding to the partial gateway. This sign would likely have survived if it were placed in the gutter pan or on top of the curb.

Table 3-2. Percent of drivers yielding at the midblock crosswalk in Allegan when the RRFB was activated and not activated, during baseline and after the gateway was installed.

Before gateway Installed		After gateway Installed			
			Sept	Oct	Nov
Baseline	18%	gateway alone	82%	50%*	57%*
RRFB	65%	gateway + RRFB	95%	98%	96%
* The RRFB on the north edge of the crossing was lost due to an impact.					

Installing a Gateway at Only One Leg of an Intersection

Sometimes pedestrian exposure is much higher at the crosswalk on one side of an intersection than the other. This study examined if a gateway treatment installed at the busier leg produced an increase in yielding on the crosswalk at the untreated leg of the intersection. The purpose of this study was to determine if a gateway installed on one leg of an intersection had an effect on yielding at the untreated leg of the intersection.

Participants and Setting

Participants were motorists at the intersection of Main Street and Bennett Street near the downtown area of Three Rivers, Michigan. The intersection connects two churches, a park, and an elementary school. The north-south traffic (Main Street) travels in two lanes, with a middle turn lane, with a posted speed of 3O mph. The east-west traffic (Bennett Street) has a 25 mph speed limit and is controlled with stop signs. Figure 3-13 shows a diagram of the intersection.

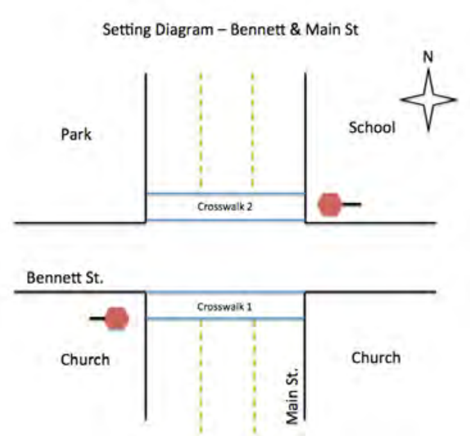


Figure 3-13. Diagram of the intersection of Main Street and Bennett Street in Three Rivers, Michigan.

Research Design
A reversal design was used to determine the effectiveness of a gateway treatment to adjoining crosswalks. Following a baseline condition to establish the percentage of drivers yielding right-of-way to pedestrians, the gateway treatment was introduced at one leg of the crosswalk and driver yielding was assessed at both legs of the crosswalk.

Results
The results are presented in Figure 3-14 show that the gateway treatment produced an increase in yielding at both crosswalks although the effect on the crosswalk leg with the gateway is somewhat larger than the effect on crosswalk leg without the gateway. Both increases in yielding were large. One reason why the gateway influenced yielding at both legs was may have been because the gateway reduced driver speed at the intersection. This reduction in speed benefits pedestrian using both the gateway treated leg and the untreated leg.

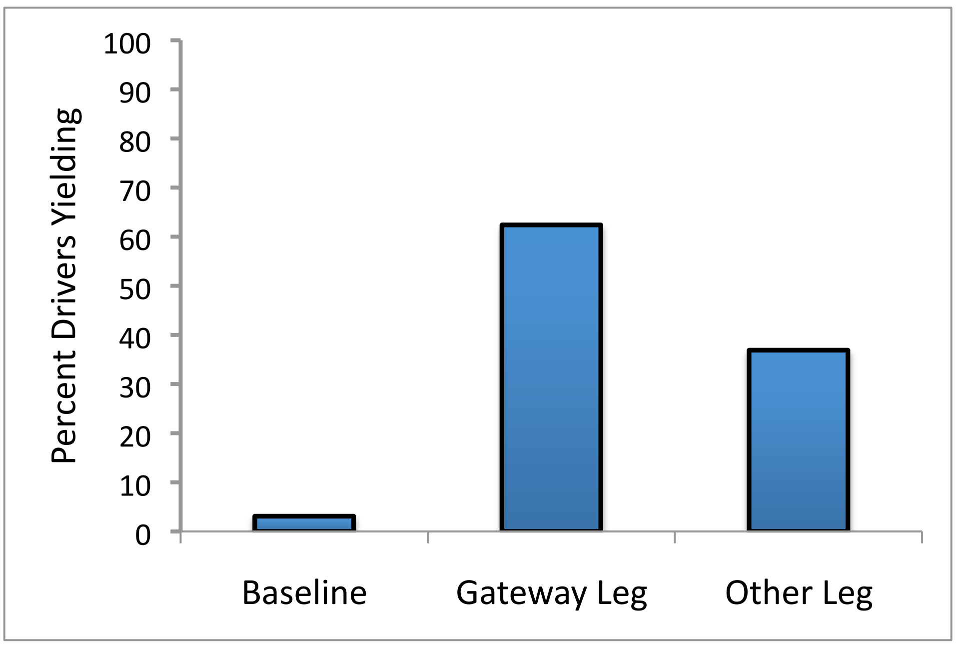


Figure 3-14. Percent of drivers yielding at the leg of an intersection with the gateway treatment and other leg of intersection that was not treated.

CHAPTER 4 - POTENTIAL ROADWAY CHARACTERISTICS INFLUENCING THE EFFICACY OF THE GATEWAY TREATMENT

Table 4-1 lists characteristics for each experimentation sites where gateway installations were installed. Most of these sites were installed during the present study, but the Trowbridge Road site, the Livernois site and the two Farmington sites were installed during an earlier MDOT contract. These have been included to increase the diversity of sites. A map of locations is provided in Figure 4-1. The data do show some trends. The gateway seems to work best at midblock crosswalks and uncontrolled crosswalks at an intersection with a minor street with stop sign control. It does not seem to matter whether the site has a refuge island or median, but it is known that the presence of these features is associated with a crash modification factor. It is also the case that a more robust gateway can be installed at a midblock site with a refuge island by installing the signs on the refuge island on top of the curb and the signs on the right edge of the road in the gutter pan or on top of the curb under permission to experiment.

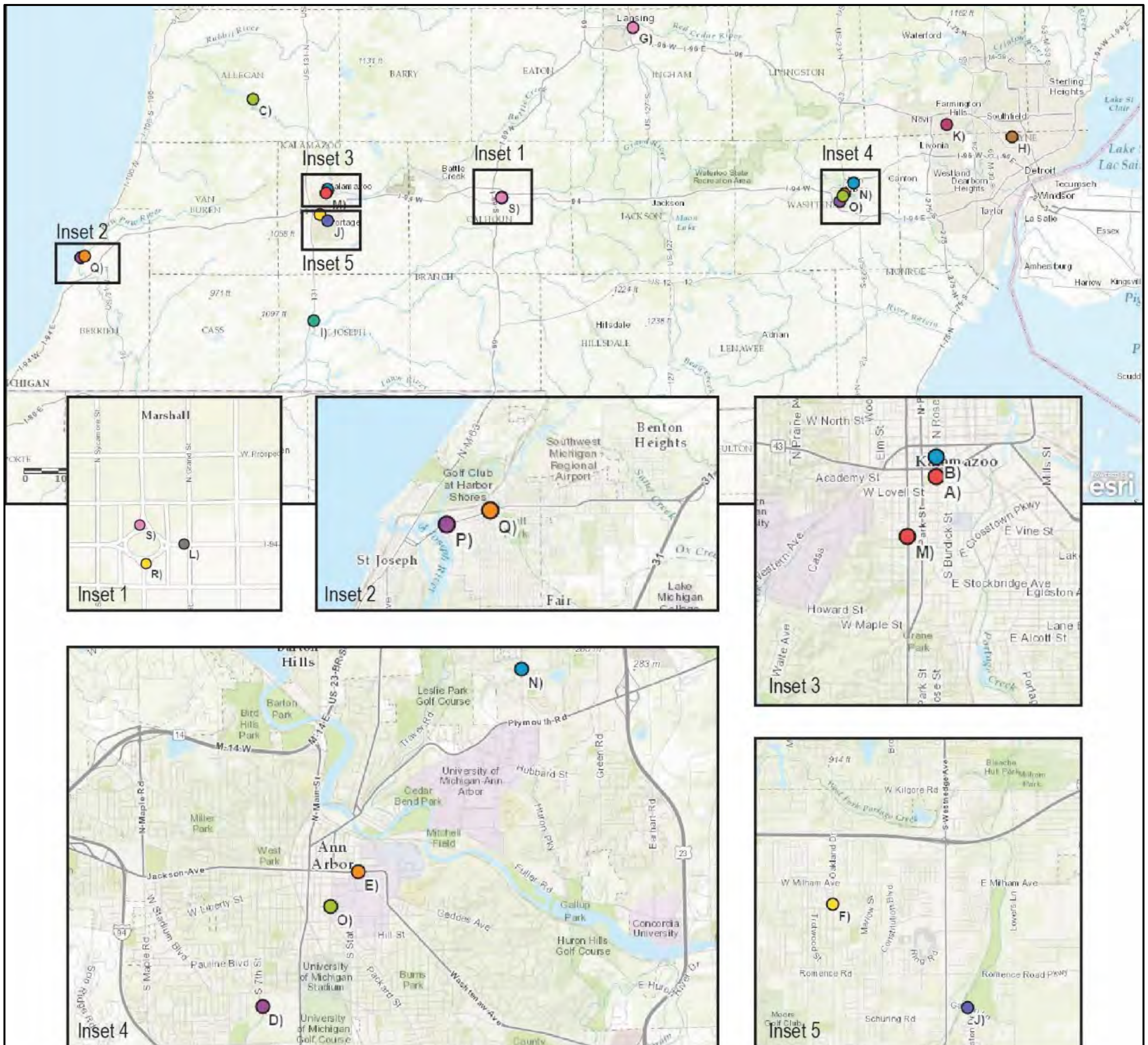
Roadway characteristics may influence the probability that drivers will yield right-of-way at a crosswalk location. One characteristic is vehicle speed, which may or may not relate to the posted speed. The probability of a driver yielding right-of-way to a pedestrian is known to be a function of vehicle speed. One reason why drivers are less likely to yield right-of-way when they are travelling fast is that it takes more effort and time to brake. Another reason is that drivers show increased tunnel vision with increasing vehicle speed. Under these conditions they may not detect pedestrians entering the crosswalk from the side of the roadway. Unfortunately, we do not have data on operating speeds on most of the roads studied in this series of experiments. Speed seems to be the major factor with 61% of drivers on average yielding to pedestrians on 35 mph road, 78% of drivers yielding on average to pedestrian's 30 mph roads, and 83% of drivers yielding on 25 mph roads.

Another characteristic that might influence whether a driver yields right-of-way to a pedestrian is ADT. However, The Gateway worked very well at several sites with a high ADT and a speed limit of 30 mph (E. Huron St., Trowbridge Rd., and Livernois Ave.) but it did not work well at two sites with a high ADT and a speed limit of 35 mph (Oakland Rd. and Westnedge Ave.). The average percentage of drivers yielding to pedestrians averaged 79% for when AADT was below 10,000, 69% when AADT was between 10,000 and 20,000, and 71% when AADT was over 20,000. Overall this effect size for ADT was smaller than that for speed. Yielding averaged 69% with one vehicle travel lane in each direction and 76% with two motor vehicle travel lanes in each direction. Caution should be used when interpreting these results because they are not based on many sites. However, it does appear that speed may be a larger factor than AADT and that the Gateway treatment may work best on roads with a 25 or 30 mph speed limit.

Another characteristic may be the number of engineering devices present that influence driver yielding right-of-way behavior. For example, advance yield or stop lines, a RRFB, or a PHB used in conjunction with a single R1-6 sign or a complete gateway treatment may produce higher driver yielding behavior than the presence of only one safety feature. Clear and consistent evidence exists showing a cumulative effect of multiple safety features.

Table 4-1 Select roadway characteristics for MDOT project 120239 (Research on Comparison of Alternative Pedestrian Crossing Treatments) and MDOT project 114527 (Evaluating Pedestrian Safety Improvements) and yielding results

Location	# lanes	parking	Island or Median	Midblock	AADT	Posted Speed	Baseline	Gateway	RRFB	PHB	Gate + Beacon
Midblock refuge island or median											
Rose @ KVCC Midblock	4	No	Yes	Yes	6,820	35	6%	80%	NA	NA	NA
Monroe Midblock Allegan	2	No	Yes	Yes	9,200	30	6%	82%	65%	NA	96%
7th St., N. or Pioneer Rd.	3	No	Yes	Yes	12,500	35	15%	57%	NA	NA	NA
Huron Midblock	4	No	Yes	Yes	20,100	30	62%	92%	NA	NA	NA
Oakland Trail Crossing	2	No	Yes	Yes	21,430	35	2%	39%	NA	NA	NA
Trowbridge Road	4	No	Yes	Yes	21,123	30	25%	79%	NA	NA	NA
Livernois @ 7 Mile Rd.	4	Yes	Yes	Yes	27,280	30	1%	72%	NA	62%	NA
Mean							17%	72%			
Midblock without refuge island or median											
N Main St. Three Rivers	2	Yes	No	Yes	7,500	30	6%	56%	NA	NA	NA
Garden Trail Crossing	2	No	No	Yes	2581	30	21%	75%	NA	NA	NA
Grand River Ave at Warner St.	3	Yes	No	Yes	12,905	25	20%	80%	69%	NA	85%
Mean							16%	70%			
Intersection											
West Michigan @ Grand	4	yes	No	No	11,900	30	10%	79%	NA	NA	NA
Rose @ Academy	4	Yes	No	No	6,820	35	7%	80%	NA	NA	NA
Westnedge @ Ranney	2	Yes	No	No	17,254	35	0%	47%	NA	NA	NA
Nixon @ Bluett, Ann Arbor	3	No	No	No	9,734	30	40%	89%	NA	NA	NA
Division @ Jefferson	2	Yes	No	No	9,284	25	3%	94%	NA	NA	NA
Farmington Road @State St	4	No	No	No	13,880	25	25%	82%	NA	NA	NA
Mean							14%	79%			
Traffic Circle and Roundabouts											
Roundabout @ Riverview	2	No	Yes	No	9,400	35	9%	44%	NA	NA	NA
Roundabout @ 5th St.	2	No	Yes	No	6,900	35	19%	61%	NA	NA	NA
Traffic Circle Wide	1	No	Yes	No	14,400	30	11%	32%	NA	NA	NA
Traffic Circle Narrow	1	No	Yes	No	14,000	30	13%	71%	NA	NA	NA
Mean							13%	52%			
City post on lane lines											
Curb Extension											



A) Crosswalk on Rose Street at Academy St. Kalamazoo, MI
B) Midblock Crosswalk on Rose Street North of West Water Street, Kalamazoo, MI
C) Midblock Crosswalk on Monroe St. West of Chestnut St., Allegan , MI
D) Midblock Crosswalk S 7th St. at Pioneer High School, Ann Arbor, MI
E) Midblock Crosswalk on East Huron between Thayer St. and Ingalls St. Ann Arbor, M
F) Midblock Trail Crossing on Oakland Rd. South of Milham Rd. Portage, MI
G) Midblock Crosswalk, Trowbridge Rd. East of South Harrison Rd. East Lansing, MI
H) Midblock Crosswalk Livernois Ave. North of 7 Mile Rd, Detroit, MI
I) Midblock Crosswalk North Main Street North of East Michigan Ave., Three Rivers, MI
J) Midblock Trail Crossing on Garden Ln East of South Westnedge Ave., Kalamazoo, MI
K) Crosswalk on Grand River Ave. at Warner St. Farmington, MI
L) Crosswalk on West Michigan Ave. at Grand St. in Marshall, MI
M) Crosswalk on South Westnedge Ave. at Ranney St., Kalamazoo, MI
N) Crosswalk on Nixon Rd. at Bluett Dr., Ann Arbor, MI
O) Crosswalk on South Division St. at E. Jefferson St., Ann Arbor, MI
P) Crosswalks at Roundabout on W. Main St. at Riverview Dr., Benton Harbor, MI
Q) Crosswalks at Roundabout on W. Main St. at 5th St., Benton Harbor, MI
R) SE Crossswalk Leg at the Marshall Roundabout, Marshall, MI
S) NW Crosswalk Leg at the Marshall Roundabout, Marshall, MI

Figure 4-1. Study Area Map

CHAPTER 5 – EVALUATION OF THE LONG TERM EFFICACY AND SURVIVAL OF THE GATEWAY TREATMENT

This chapter provides an examination of the long-term persistence of driver yielding right-of-way to pedestrians and the long-term survival of the gateway treatment. Data for long-term efficacy of the gateway treatment is presented in Table 5-1.

Table 5-1. Percent of drivers yielding to pedestrians during baseline, initial temporary installation, and after permanent installation at each of the treatment sites.

Crosswalk Location	**Percent of Drivers Yielding**				
	Baseline	**Temporary Installation**	**Permanent Installation**		
Follow up Period	**X**	**X**	**1 Month**	**2 Month**	**3 Month**
Nixon Rd. at Bluett Rd.	40	86	93	89	X
S 7th St. midblock North of Pioneer Rd.	15	54	64	70	X
S. Division St. at E. Jefferson St.	3	94	94	93	X
E. Huron St. west of N. Ingalls St.	40	86	X	X	X
N. Main St. North of E. Michigan Ave.	6	X	64	53	50
Roundabout E. Main St. at 5th St.	19	45	61	60	*33
Roundabout E Main at Riverview Dr.	9	43	44	44	44
Marshall Traffic Circle NE Crosswalk	13	54	71	71	50
Marshall Traffic Circle SW Crosswalk	11	29	26	38	34
S. Westnedge at Ranney St.	0	59	33	29	*NA
Monroe St. east of Chestnut RRFB Off	6	X	82	*50	*56
Monroe St. east of Chestnut RRFB On	65	X	95	98	96
Mean	19	61	66	63	
*Gateway element was identified as damaged or destroyed					

LONG TERM EFFICACY

The installation of the temporary gateway led to an increase in the percentage of drivers yielding to pedestrians at each site. During baseline conditions, yielding averaged 19% with a range of 0 to 40%. A temporary installation was evaluated after the baseline condition at each site. When the temporary gateway treatment was evaluated, yielding increased to 61% with a range of 29% to 94%. Once the permanent gateway treatments were installed for one-month yielding increased to 66% with a range of 26% to 95%. Two months after the permanent installation yielding was 63% with a range of 29% to 98%. Data collected after the first two months after permanent signs were installed was very similar to data collected with the temporary signs. The signs in Ann Arbor were installed one month later than the signs in southwest Michigan so there is no data for the third month at these sites. The data from the sites in southwest Michigan were similar for the third month with exception of two sites that had elements of the gateway damaged. The site at the Roundabout at 5th in Benton Harbor lost one of the two signs placed on the edge lane line at the entrance to the roundabout. This sign was sheered from its base. At the site at Westnedge at Ranney in Kalamazoo, the delineator was seriously damaged reducing the gateway effect. This sign showed evidence of many more strikes than other signs. Many of the signs showed no evidence of being struck. If one assumes the data will hold up for the third month in Ann Arbor, the mean would be 65%, which is the same as the level produced by the temporary gateway installations. It should be noted that the signs are much more effective at some sites. However, in all cases pedestrians did not need to wait long to cross after the gateway was introduced. For example, with 50% yielding every second driver yields; even with 30% yielding nearly every third driver yields. However, with low baseline levels of 0%, 3%, 6% or 9%, less than one driver in ten yields.

SURVIVAL

Signs were checked for damage on a regular basis. Many signs showed no evidence of being struck. Generally, signs mounted on a curb showed no evidence of being struck and none were damaged. Two of the signs installed in the roadway with flush mounted bases were seriously damaged. Only one of the flexible delineator posts was destroyed and this was at the site with the highest number of strikes. Preliminary data suggest that the use of a curb type bases mounted in the gutter pan or signs mounted on top of the curb may show good long-term survival. The use of the flexible delineator post looks like it can survive, however the data at Westnedge and Ranney show this sign can be destroyed if it is struck on a regular basis. It should be noted that one sign that was destroyed and the other that was severely damaged were signs with flush mounted bases located on the edge lane line. These data suggest that signs mounted flush to the street are less robust than the signs mounted on curb type bases. It is unlikely these signs would have been damaged if they were placed on top of the curb.

In climates that require plowing snow in winter, it is necessary to install the signs after the snow season ends and to remove the signs before the start of the snow season. Because the initial cost of installation is greater than the cost of removal and reinstallation, removal for winter operations is not likely a major burden for the use of these signs. Typically pedestrian activity is greater during the spring, summer and fall than during winter months, particularly in areas with high tourism exposure. This is key because the only signs that would likely survive in winter are those mounted on the top of the curb at the right side of the road and those mounted on top of the curb on a refuge or median island. However, it is not certain whether the snow loading from the plow could damage the signs if it pushes them to the side.

CHAPTER 6 – TYPICALLY COSTS FOR INSTALLATION AND MAINTENANCE OF THE GATEWAY TREATMENT (NOTE INSTALLATION COST MAY VARY)

Table 6-1. Costs for installation and maintenance of the gateway treatment

COST OF VARIOUS GATEWAY ELEMENTS		
R1-6 sign mounted on a curb type base	$300	
R1-6 sign mounted a base cemented on top of the curb beside the road	$200	
Cost of a flexible delineator post, base, cap and epoxy	$130	
INSTALLATION TIME (MOBILIZATION AND TRAVEL NOT INCLUDED)		
R1-6 Sign on a curb base mounted in the roadway	5 min.	
R1-6 sign on a base cemented to the top of the curb	5 min.	
Flexible Delineator mounted in the roadway	10 min.	
INSTALLATION MATERIAL COST AND TIME, PER CONFIGURATION		
FOUR-LANE CROSSING WITH REFUGE ISLAND	**COST**	**TIME**
Gateway, curb mounted R1-6 signs with curb bases	$1,820	30 min.
Gateway, curb mounted R1-6 signs, robust delineator on white lane lines	$1,480	40 min.
THREE-LANE CROSSING WITH NO REFUGE ISLAND		
Gateway with curb mounted R1-6 signs with curb bases	$1,210	20 min.
TWO-LANE CROSSING WITH NO REFUGE ISLAND		
Gateway with curb mounted R1-6 signs with curb bases	$ 910	15 min.
Note: Cost for all configurations would be lower with edge signs placed on top of curb. This configuration requires FHWA request for experimentation		
INDIVIDUAL INSTALLATION COST ITEMS		
R1-6 Sign mounted on a curb base	$190	
R1-6 sign mounted on top of curb beside roadway	$190	
Flexible delineator post installed on white lane line	$110	

All signs can be removed and taken out for winter operation very quickly. The flexible delineators come with a recessed cap that protects the base from water damage. The curb bases are removable and the holes need to be filled with silicone caulking to protect the roadway from water freeze/thaw damage during winter.

Table 6-2. Removal and reinstallation times for gateway treatment

Removal of curb type base and sign	2 min.
Reinstallation of curb type base and sign	2 min.
Removal of sign mounted on top of curb	1 min.
Reinstallation of sign mounted on top of curb	1 min.
Removal of flexible delineator, install cap for winter	40 sec.
Reinstallation of flexible delineator, remove cap in spring	90 sec.

CHAPTER 7 - CONCLUSIONS

The results of the first series of studies explored several gateway configurations influencing the efficacy of the gateway treatment. One hypothesis that was confirmed was that the narrowness of the gap between the signs was inversely related to the treatment effect. This hypothesis was confirmed with narrow gaps leading to larger increases in driver yielding right-of-way to pedestrians at several different types of crosswalk applications.

Another hypothesis tested was whether the sign message itself had an effect on driver yielding behavior. It was found that the blanks configuration was significantly less effective than the gateway configuration with the sign message present.

A configuration analysis also showed that the position of the sign is a critical factor for driver yielding behavior.

- Gateway treatment positions used in isolation resulted in lower driver yielding right-of-way to pedestrians than the full gateway.
- Signs placed on the white lane line alone exerted more control over driver yielding behavior than the edge positions alone at all sites, but less yielding than the full gateway treatment.

It appears that the effect is greatest when motorists need to drive in a lane between two signs. However, the effects produced by the partial gateway treatment show that if a sign is hit during a season and not replaced until the signs are reinstalled after winter, the partial gateway treatment would still be of some benefit to pedestrians.

Another finding was the reduction in speed associated with the presence of the gateway treatment. Drivers began slowing at the dilemma zone and were travelling 10 mph slower when they entered the crosswalk at the only site where speed was measured. This speed reduction should decrease the probability of hitting a pedestrian, as well as the seriousness of a crash should one occur.

Although this study and previous studies (9) demonstrate that the gateway treatment produced changes in driver yielding behavior at crosswalks on multilane roads that can rival treatments one and two orders of magnitude more expensive to install, it is also important to show that this treatment will not require excessive maintenance efforts. In locations where plowing is not an issue the signs can remain up year round. However, in areas where snow removal is an issue, the signs would need to be removed in winter. Most of the signs tested can be removed and reinstalled quickly after the initial installation. Although in-street signs are designed to rebound after being struck, sign survival with multiple strikes could be an issue.

Chapter 2 examined two configurations that could increase the survival of the gateway treatment. The two configurations tested, which showed increased sign survival, only produced moderate reductions in the efficacy of the gateway treatment. First, installation of the sign on top of the curb face was associated with only a small reduction in the treatment effectiveness. Signs on top of the curb face are less likely to be struck than signs placed in the gutter pan and do not present a problem for sweepers or drainage issues. However, this type of configuration would be less effective at locations with on-street parking where parked vehicles could screen the view of a sign as well as pedestrians. One solution to this problem would be to install a curb extension. The curb extension would prevent parked cars from screening the view of the pedestrian, as well as allowing the installation of a R1-6 edge signs on top of the curb.

The most vulnerable element of the gateway configuration are the signs placed on white lines separating lanes carrying traffic in the same direction. The use of a robust yellow green flexible delineator device can add to the survival of the gateway treatment. The delineator selected was tested by the Texas Transportation Institute and found to take 100 strikes at 60 mph. This type of a device should have a long lifespan on urban roads with speed limits of 35 mph or less. If there is a median or refuge island, the use of curb top placement of the R1-6 edge signs and a delineator at the lane line should provide a trouble free installation for many years.

Most of the applications studied in an earlier MDOT study examined the gateway treatment efficacy at midblock crosswalks and crosswalks at uncontrolled locations on an arterial or collector road at the intersection of a stop-controlled road. Chapter 3 examined the gateway treatment in a variety of new crosswalk applications, including traffic circles, roundabouts, freeway entrance ramps, and trail crossings. The results of this study showed that the gateway treatment was less effective at traffic circle crosswalks, particularly at the wider configurations. The gateway treatment was also less effective at roundabout locations, particularly at crosswalks exiting the roundabout. The treatment at freeway entrance ramps only produced marginal increases in yielding behavior. The gateway treatment is therefore not recommended for this type of application. One reason why the gateway treatment was ineffective at this type of application is that drivers are accelerating as they approach an entrance ramp and are less likely to yield right-of-way to pedestrians. The gateway treatment was highly effective at one of the two trail crossings but only moderately effective at the second crossing that had a higher operating speed.

Preliminary data suggest:

- That the gateway treatment is most effective at midblock crosswalk locations, uncontrolled crosswalk locations at an intersection with a stop-controlled road, and trail crossings.
- Data also indicated that a gateway installed at an RRFB location could bring yielding behavior to a level that comes close to that produced at a traffic signal.
- Data also suggest that the gateway may not be as effective on roads with a speed limit above 30 mph if the ADT is over 15,000.

Chapter 5 provided preliminary evidence of the long-term persistence of gateway increases in drivers yielding right-of-way to pedestrians over time and the long-term survival of the gateway treatment. Because the signs were only installed for two or three months, supplemental data will be required in order to provide clear results. However, the signs did maintain their effectiveness in Ann Arbor over a two-month period and at the sites in the southwestern side of the state for a three-month period.

Preliminary data on sign survival indicate that gateway signs mounted in the roadway on installable curb bases may be more robust than those installed flush with the roadway, and that the robust delineator installed on a lane line can sustain many hits but may not survive for an entire season at sites with higher speeds and ADT. At locations with on-street parking, the edge signs need to be placed on the parking lane line. However such placement would make them very vulnerable to turning vehicle movements. Truck traffic hitting the signs likely would damage the signs. One alternative mentioned above would be the use of a curb extension at the crosswalk. This would allow for either gutter pan placement, curb top placement or placement in the roadway at the leading edge of the curb extension.

Chapter 6 provided information on materials and installation costs for each of the elements of the gateway treatment. These data show that the gateway treatment is a relatively inexpensive treatment. Most items can be removed easily in winter and reinstalled easily in the spring. Estimated removal and reinstallation costs were also provided.

Although this treatment increases the percentage of drivers yielding to pedestrians at crosswalks with two or more travel lanes in each direction, it is not clear whether it would be associated with a reduction in crashes at these sites. One way to increase the likelihood that gateway treatment reduces crashes would be to combine it with advance stop or yield markings (15,16,17,18,19). It is also known that in-street signs are associated with a reduction of vehicle speed at crosswalks (7). Future research should determine whether the full gateway treatment consistently leads to a larger speed reduction than a single in-street sign. Such a finding would be important because the relationship between speed reduction and reduction in crash severity has been clearly established (24).

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APPENDIX A

STATISTICAL DATA ANALYSIS

The purpose of this section is twofold. First, details regarding the statistical methods used to analyze the outcomes of the studies are explained. Second, the outcomes themselves are presented. Because the research was carried out at different Kalamazoo locations under a variety of conditions the research design, methods of analysis, and results are presented separately for each of the following sites: (1) Rose Street at Kalamazoo Valley Community College (KVCC), (2) Westnedge Avenue at Ranney Street, and (3) Rose Street at Academy.

Rose Street-KVCC Site

Research Design

The data collected at the Rose Street-KVCC site were obtained under a 14-phase time-series design that included 68 observation days. These data are presented in Figure 1. The condition labels for each phase in the 14-phase sequence are as follows: (1) Baseline, (2) Blanks, (3) Gateway, (4) City Post, (5) Gateway, (6) City Post, (7) Gateway, (8) City Post, (9) Baseline, (10) Blanks, (11) City Post, (12) Gateway, (13) Baseline, and (14) Blanks. This complex design provides elaborate replication components that allow repeated demonstrations of intervention effects.

Visual Analysis

Phases 1, 9, and 13 were exposed to the Baseline condition. It can be seen in Figure 1 that the yielding percentages are very low but similar for these three phases. The Blanks condition was applied during phases 2, 10, and 14; each of these phases has a yielding percentage that can be seen to be approximately 30 points higher than during adjacent baseline phases. The Gateway condition was applied during phases 3, 5, 7, and 12. It can be seen that the yielding percentages during these phases are over 70 points higher than during nearby baseline phases. The City Post condition was applied during phases 4, 6, 8, and 11. The yielding percentages for these phases are over 50 points higher than for baseline phases that are near them in the time sequence.

Hence, a visual analysis of the results indicates that yielding percentages are very low during all baseline phases and that yielding is much higher for each non-baseline condition. Formal statistical analyses that confirm these visual impressions and provide detailed quantitative evaluations are described next.

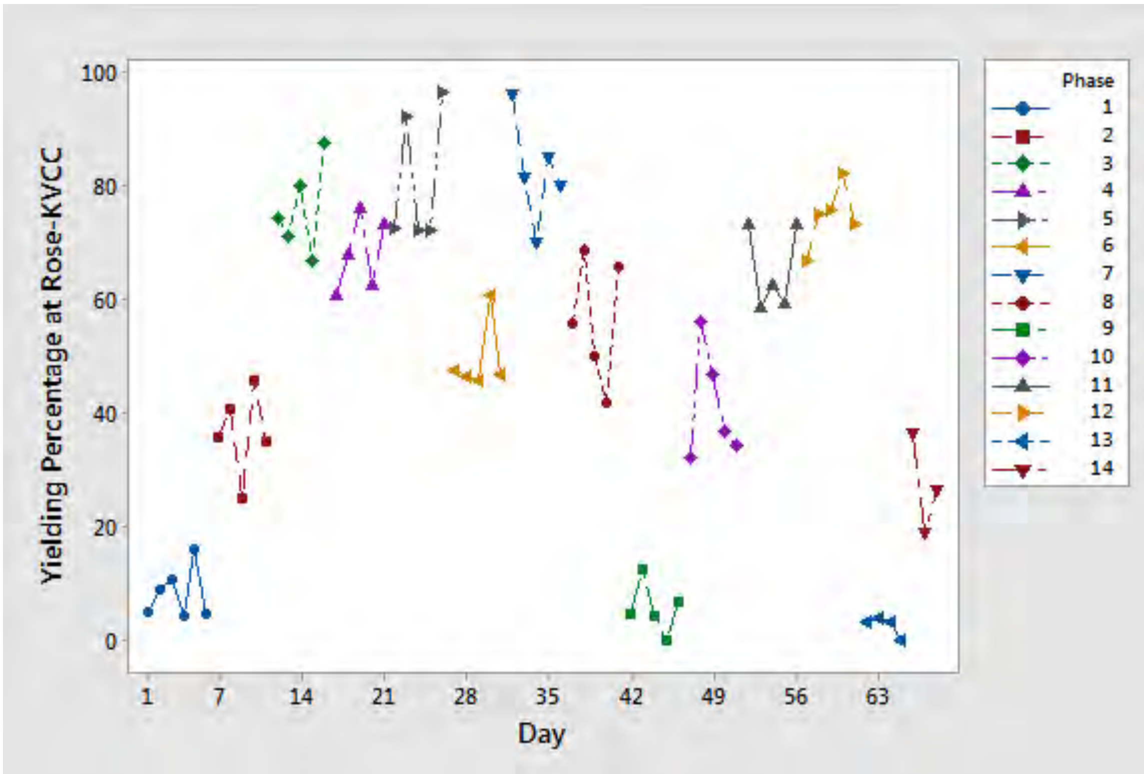

Figure 1. Yielding Percentage During 14 Phases(Rose Street-KVCC Site – Daytime).

Statistical Methods

Modeling Approach

A time-series regression intervention analysis of the type described in Huitema (2011; Chapters 18-21) was carried out on the 14-phase design implemented at the Rose-KVCC site. This modeling approach begins by fitting a complex model that accommodates several types of intervention effects and errors; subsequent analyses are then carried out to evaluate the necessity of retaining the various parameters in the initial model and to evaluate the adequacy of potentially simpler models.

The initial analysis involved fitting a complex (28-parameter) model; additional analyses summarized in Table 1 were then carried out to determine if simpler models adequately describe the data.

Table 1. Analyses Used in Model Identification and Evaluation (Rose Street-KVCC Site – Daytime)

1. *Model-comparison test*. The comparison of the initial Full Model (including level change and trend change parameters) versus the Restricted Model (including level change parameters only) yields $F = 0.38$ ($df = 14, 40$) and $p = 0.97$. It is concluded that within-phase trend and trend change parameters are not necessary and that the simpler (level change only) model is satisfactory.
2. *Test for homogeneous within-condition phase levels*. An overall F-test for equality of phase levels within all conditions is rejected ($p = 0.04$). Separate follow-up F-tests (computed for each condition) reveal that three of four conditions have homogeneous within condition phase levels. One condition (City Post) has statistically significant ($p < 0.04$) heterogeneity of within-condition phase levels, but the degree of the heterogeneity is insufficient to invalidate pooling. Hence, levels among phases within the four treatment conditions are treated as homogeneous in the final intervention analysis.
3. *Test of the assumption of independent errors*. Autocorrelation among residuals of the final analysis (a 4-condition level change model) is not present ($r_1 = -0.09$, Huitema-McKean test p-value = 0.98; Ljung-Box test on the complete autocorrelation function through lag-17 yields p-value = 0.85). Autoregressive parameters are not required in the model because the errors appear to be independent.
4. *Test of the assumption of a normal error distribution*. The Anderson-Darling test applied to the residuals of the 4-condition level change model does not reject (p-value > 0.05) the normality assumption. Approximate normality is implied.
5. *Test of the assumption of homogeneous of within-condition variances*. Levene's test rejects

($p < 0.05$) the hypothesis of variance homogeneity. Subsequent tests comparing condition levels are modified (using Welch-*F* and Games-Howell-*q* approaches) to accommodate this heterogeneity.

Model Simplification

One model simplification that is sometimes possible involves the removal of parameters describing trend within phases or conditions. The first test listed in Table 1 is a "model comparison" test that determines whether measures of trend within phases are required in the model. Because this test is clearly not statistically significant ($p = 0.97$) it is concluded that the data are well modeled without parameters describing trend within phases. The only parameters needed to describe the effects of the interventions are those that describe the change in level from one phase to the next.

A second concern in evaluating the adequacy of the initial model is the variation among the phase levels within conditions. There were three Baseline phases, three Blanks phases, four Gateway phases, and four City Post phases. If the levels of the three or four phases within each of these conditions are essentially homogeneous it is sensible to pool data. That is, on a condition-by-condition basis, consolidate the data from the various phases within each condition.

Alternatively, if the phase levels within conditions are not homogeneous it may be misleading to pool the data; to do so in this case is to imply that a single condition is involved when actually it may be important to consider different variants of a condition. The decision made with respect to pooling leads to a major difference in the complexity of the final analysis in this experiment. Without pooling there are 14 phases and 182 potential comparisons to be analyzed; with pooling there are just four conditions and six pairwise comparisons. This simplicity occurs because a single parameter adequately describes a condition level regardless of which phase within the condition is involved. For these reasons formal statistical tests of the homogeneity of the phase levels within conditions were carried out; they are summarized as the second entry in Table 1.

The overall test rejects the hypothesis that within condition phase levels are homogeneous ($p = 0.01$). This implies that the phase levels are heterogeneous within at least one condition. A separate test of homogeneity of phase levels was then carried out for each of the four conditions. These four tests revealed that only the City Post condition has heterogeneous phase levels. Homogeneity of the phase levels is present within the Baseline, Blank, and Gateway conditions.

Although strict heterogeneity of phase levels within the City Post condition was identified, the more important issue is deciding whether the heterogeneity is large enough to be of practical importance in describing the overall effects of the interventions. It turns out that it is not. This was concluded because the comparison of each City Post phase level with the overall levels for the other three conditions yields the same pattern regardless of the phase chosen. That is, regardless of which City Post phase is chosen for comparison with the three remaining conditions (viz., Baseline, Blanks, and Gateway) the order of effectiveness is always the same: Gateway > City Post > Blanks > Baseline. Although this pattern is not easily observed in Figure 1, it is fairy obvious in Figure 2. Notice that the Baseline condition has the lowest yielding percentage regardless of which of the three Baseline phases is considered, the Blanks condition is always second lowest, the City Post yielding percentage is second highest regardless of the phase, and the Gateway condition always produces the highest yielding percentage. There is no instance in which this pattern does not hold. Because this ordering is constant for the four phases within the City Post condition, these phases were pooled (just as they were for the other conditions) to provide a single level estimate for this condition.

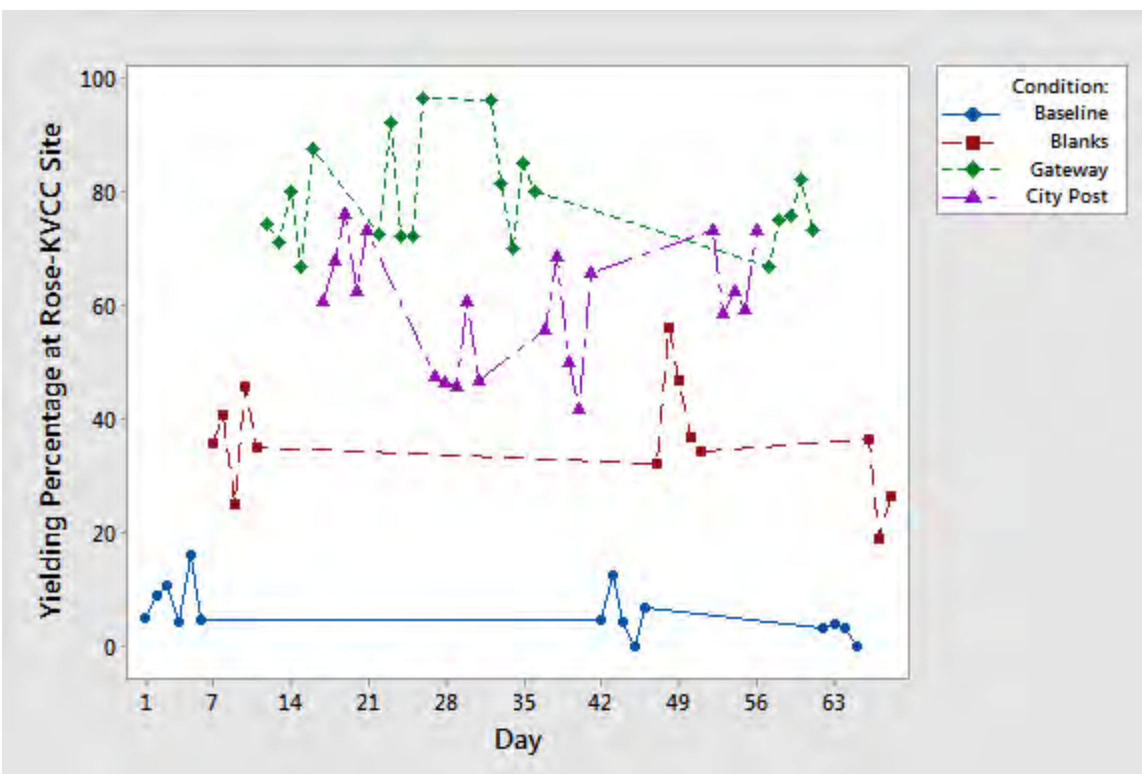

Figure 2. Yielding Percentage During Four Conditions (Rose-KVCC Site – Daytime).

Final Simplified Model

The model comparison test and the homogeneity tests described above were applied in order to justify simplifying the initial complex model. It was concluded from these tests that trend parameters were not necessary and that phases within conditions could be pooled. These decisions led to a far simpler model, which is written as follows:

$$Y_t = \beta_0 + \beta_1 D_{1t} + \beta_2 D_{2t} + \beta_3 D_{3t} + \varepsilon_t$$

where

Y_t is the yielding percentage measured on day *t,*
β_0 is the regression intercept,
β_1 is the level change between the Baseline and Blanks conditions,
D_{1t} is the dummy variable indicating the Blanks condition on day *t*,
β_2 is the level change between the Blanks and Gateway conditions,
D_{2t} is the dummy variable indicating the Gateway condition on day *t*,
β_3 is the level change between the Gateway and City Post conditions,
D_{3t} is the dummy variable indicating the City Post condition on day *t*, and
ε_t is the error of the model.

Whereas the original 14-phase model has 28 parameters, notice that the simplified four-condition model has only four parameters. This simplification results in a more transparent interpretation of parameters, increased power of the inferential tests, and narrower confidence intervals.

After the simplified model was initially identified it was necessary to evaluate its adequacy. Entries 3, 4, and 5 in Table 1 focus on three issues relevant to evaluating this model. These issues are all related to the assumptions regarding the properties of the errors of the model. These assumptions are relevant because the inferential tests rest on them.

The first assumption is that the errors are independent. This assumption is violated if the residuals are autocorrelated. It can be seen in Table 1 that the residuals of the fitted four-condition level-change model are not autocorrelated. Both the H-M and L-B tests for autocorrelation yield very high *p*-values (viz., 0.98 and 0.85, respectively). This implies that autoregressive parameters are not needed and that independence of errors of the adopted model can be assumed.

The second assumption is that the distribution of the model errors is normal. Table 1 shows that the Anderson-Darling test of normality does not reject this assumption; approximate normality is accepted. This implies that neither transformations of the outcome measure nor alternative estimation methods are required for adequate tests of intervention effects.

The last assumption is that of homogeneous within condition variances. As can be seen in Table 1 (last entry) this assumption is violated. It can be seen in Table 2 that the variance for the Baseline condition is considerably smaller than the variance associated with each of the other three conditions. For this reason the conventional tests applied to evaluate intervention effects under this model were modified (using Welch-*F* and Games-Howell-*q* methods) to accommodate potential problems associated with heterogeneous variances.

In summary, all assumptions except homogeneity of variance are met for the proposed outcome analysis. Plots of the residuals of the model (not shown here) confirm the results of the tests summarized above; it is concluded that the identified four-parameter intervention model is appropriate for the final analysis if modified tests that accommodate heterogeneity of variance are used. The results of applying this analysis are presented below.

Results

Measures of the effects of introducing condition changes (Blanks, Gateway, and City Post) at the Rose Street – KVCC site are provided in this section. These measures are based on the identified four-condition time-series regression intervention model that was identified above. Estimates of the level and variance parameters associated with the four conditions (i.e., Baseline, Blanks, City Post, and Gateway) are listed in Table 2. The level parameters are essentially the average yielding percentages for the four conditions. Notice that very large effects seem obvious by simply inspecting the yielding percentages shown in Table 2 for the four conditions.

Inferential tests on differences among the condition levels confirm impressions based on simple inspection. The overall test for differences among the condition levels yields an *F*-ratio of 378.23 and a *p*-value that is < 0.001. Hence, there is no doubt that at least one condition level differs significantly from the other three. Pairwise comparisons among the four conditions were carried out to identify the specific condition levels that differed significantly from each other.

Table 3 lists the pairwise differences among the estimated levels, the results of inferential multiple-comparison tests on these differences, and the standardized effect sizes. Notice that each contrast of two conditions is associated with a *p*-value that is less than .005; hence, all pairwise comparisons are statistically significant. More important, the standardized effect sizes indicate that each two-condition comparison easily exceeds the definition of a large effect size using Cohen's criterion (viz., $\geq .80$). Similarly, very large effects of the interventions are revealed by the $\hat{\eta}^2$ statistic, which is 0.906; this is interpreted as the proportion of the total variation in daily yielding behavior that is explained by the intervention conditions.

A graphic representation of the level differences can be seen in Figure 3 as the dots in the center of the illustrated lines. Numbers 1, 2, 3, and 4 in this figure correspond to the four conditions previously described as Baseline, Blanks, Gateway, and City Post, respectively. Hence, "2 – 1" shown in the upper left of the figure identifies the row with a line that contains a dot corresponding to the difference between the level of the first condition (Baseline) and the level of the second condition (Blanks). Notice that this dot falls above a point on the abscissa that is about half way between 20 and 40; actually it is exactly 30.34. (This is also the value shown in Table 3 as the difference between the levels for the these conditions.) The left and right ends of the lines in the figure indicate the lower and upper limits on the simultaneous 95 percent confidence intervals. We can be at least 95 percent confident that the whole set of intervals is correct; that is, we are at least 95 percent confident that the whole collection of six intervals indeed trap the true process effect (i.e., level differences) within the limits illustrated here. Notice that none of the intervals is near the zero line; this means that zero is far from being a credible value for the true difference between any pair of true condition means.

Although the conventional confidence coefficient of 95 percent has been used in constructing the lines in this figure, the much more stringent confidence coefficient of 99.5 could also be used. If this were done it would still be found that none of the intervals would contain zero and the set of intervals would be consistent with the set of results shown in column 3 of Table 3. Notice that each *p*-value in this table is less than .005. This is simply an alternative way of indicating that each of the six pairwise differences among condition levels far exceeds sampling error and, more importantly, represents a large and persuasive effect of the interventions.

Table 2. Yielding Level and Variance for Four Conditions (Rose-KVCC Site – Daytime)

Condition	**Yielding Percentage Level**	**Variance**
1. Baseline	5.83	19.65
2. Blanks	36.17	96.92
3. Gateway	78.52	82.15
4. City Post	59.82	112.96

Table 3. Differences Among Yielding Levels, Familywise *p*-values, and Standardized Effect Sizes (Rose-KVCC Site – Daytime)

Conditions Compared	**Level Difference**	**Familywise *p*-value**	**Standardized Effect Size**
Blanks - Baseline	30.34	< 0.005	3.38
Gateway – Baseline	72.69	< 0.005	8.10
City Post - Baseline	53.99	< 0.005	6.02
Gateway - Blanks	42.35	< 0.005	4.72
City Post -Blanks	23.65	< 0.005	2.64
City Post - Gateway	-18.70	< 0.005	-2.08

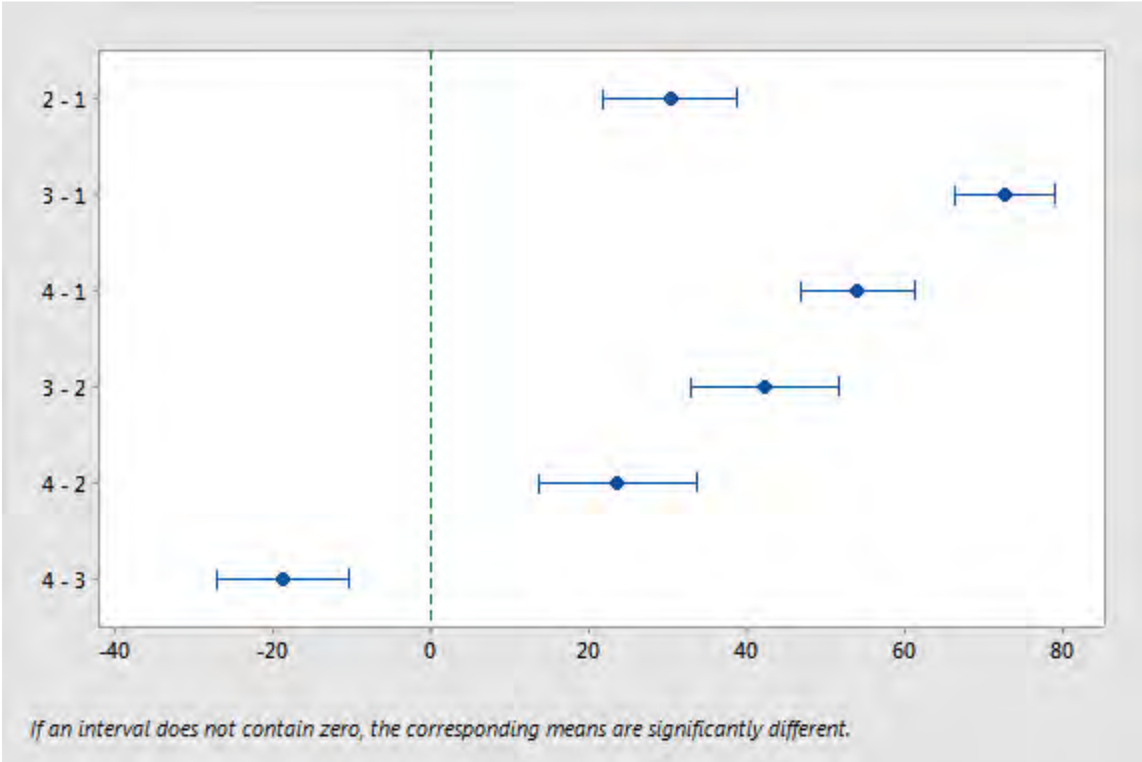

Figure 3. Simultaneous 95 Percent Confidence Intervals on Level Differences for Each Pair of Conditions (Rose-KVCC Site – Daytime).

Rose Street at KVCC Site (Night)

The analysis presented above is based on the daytime data collected at the Rose Street-KVCC site; a second experiment was carried out at the this site at night. The nighttime data are analyzed here.

Research Design

The design used at night is much simpler than the daytime version because only four phases (rather than 14) are involved and the number of data collection days is 18 (rather than 68). Data were collected under three conditions: Baseline (phases one and four), Gateway (phase 2), and City Post (phase 3). These data can be seen in Figure 4.

Visual Analysis

It is obvious in Figure 4 that the yielding percentage is very low during the Baseline phases (one and four) and that both experimental conditions are associated with much higher yielding. The rank order of the effectiveness of the different conditions appears to be quite consistent with the findings reported earlier for the main (daytime) study at this site.

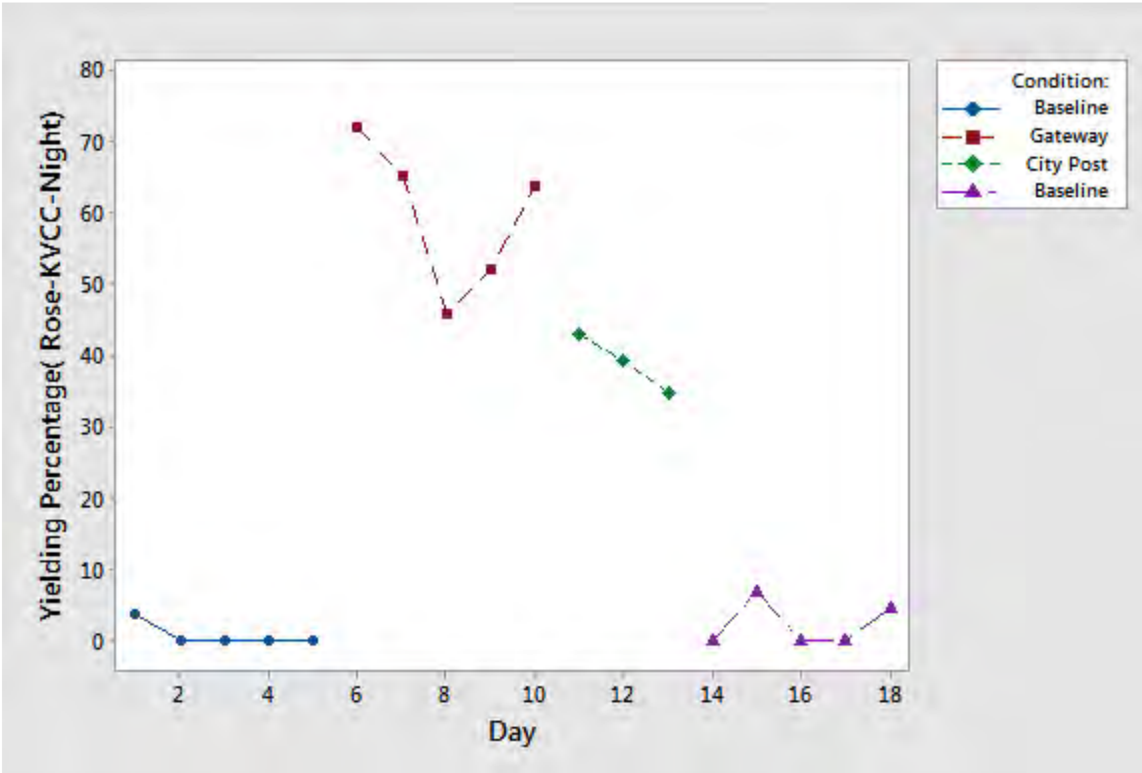

Figure 4. Yielding Percentage Under Baseline, Gateway, and City Post Conditions (Rose-KVCC Site – Night).

Statistical Methods

The statistical analysis of these data is similar to the approach described earlier in detail for the daytime data. The nature of the nighttime design, however, leads to several simplifications in the data analysis.

Model Identification

A summary of the tests used to identify the most adequate model are shown below in Table 4. Tests shown in the first two entries support the use of a three-condition level-change model with pooled baseline phases. Hence, the final model has three parameters: one describes the level of the Baseline condition, one describes the level change from Baseline to Gateway conditions, and one describes level change from Gateway to City Post conditions. This model also provides information needed to evaluate the difference between Baseline and City Post conditions.

Table 4. Summary of Tests Used in Model Identification for the Rose-KVCC Nighttime Data

1. *Model-comparison test*. The comparison of the Full Model (including level change and trend change parameters) versus the Restricted Model (including level change parameters only) yields F = 0.79 (df = 4, 10) and p = 0.56. It is concluded that within-phase trend and trend change parameters are not necessary and that the simpler (level change only) model is satisfactory.
2. *Test for homogeneous within-condition Baseline phase levels*. An F-test for equality of the two Baseline phase levels is retained (p = 0.37); the difference between the two is easily within the range expected from sampling error alone. Hence, the data from the two Baseline phases are treated as homogeneous in the final intervention analysis.
3. *Test of the assumption of independent errors*. Autocorrelation among residuals of the final analysis (a 3-condition level change model) is not present (Durbin-Watson statistic = 1.74; H-M statistic = 1.31, p = .19; Ljung-Box test on lag-1 autocorrelation yields Q = .30, p-value = 0.58). Autoregressive parameters are not required in the model because the errors appear to be independent.
4. *Test of the assumption of a normal error distribution*. The Anderson-Darling test applied to the residuals of the 3-condition level change model does not reject (p-value = 0.19) the normality assumption. Approximate normality is implied.
5. *Test of the assumption of homogeneous of within-condition variances*. Levene's test rejects (p = 0.05) the hypothesis of variance homogeneity. Subsequent tests comparing condition levels are modified (using Welch-F and Games-Howell-q approaches) to accommodate this heterogeneity.

Final Simplified Model

Test results shown as entries 3, 4, and 5 in Table 4 lead to the conclusion that the assumptions of normality and independence of the errors are approximately met; the assumption of homogeneous variances is not met. Consequently, the final tests for the identified three-parameter model are modified using Welch-F and Games-Howell-q methods for accommodating variance heterogeneity. The outcome of applying these methods is presented next.

Results

An inspection of the condition levels (Table 5) and the differences among them (Table 6) leaves no doubt that large effects were obtained. The standardized effect sizes listed in Table 6 are consistent with this conclusion. In addition, most of the variation in the experiment is explained by the interventions ($\hat{\eta}^2$ statistic = 0.96).

Inferential tests and confidence intervals essentially eliminate the argument that either the overall results or any individual difference between condition levels may have occurred only as a result of chance. The Welch-*F* omnibus test for differences among all condition levels yields a value of 155.23 ($p < .001$). Hence, the observed differences among the three condition levels are much too large to be reasonably attributed to sampling error. The Games-Howell multiple comparison test applied to each individual pairwise difference between condition levels reveals a statistically significant ($p < .02$) effect for each comparison.

Correspondingly, the simultaneous 98 percent confidence intervals can be seen in Figure 5. Note that none of the intervals traps zero; we can be 98 percent confident that the whole set of intervals trap the true difference between condition levels. Because none of the intervals traps zero it can be concluded that zero is not a credible value for the true effect of any contrast.

A comparison of the results of the daytime and nighttime results reveals a marked consistency in both the overall patterns and the specific outcome effects. In both cases the Baseline yielding level is less than six percent, the Gateway level is the highest (roughly 60-80 percent), and the City Post level is intermediate at roughly 35-60 percent.

Table 5. Yielding Level and Variance for Three Conditions (Rose-KVCC Site – Nighttime)

Condition	**Yielding Percentage Level**	**Variance**
1. Baseline	1.49	6.22
2. Gateway	59.77	111.58
3. City Post	38.92	16.35

Table 6. Intervention Effect Estimates, Familywise *p*-values, and Standardized Effect Sizes (Rose-KVCC Site – Nighttime)

Conditions	**Level Difference**	**Familywise *p*-**	**Standardized**

Compared		value	Effect Size
Gateway - Baseline	58.28	< 0.02	9.76
City Post - Baseline	37.43	< 0.02	6.27
City Post - Gateway	-20.85	< 0.02	-3.49

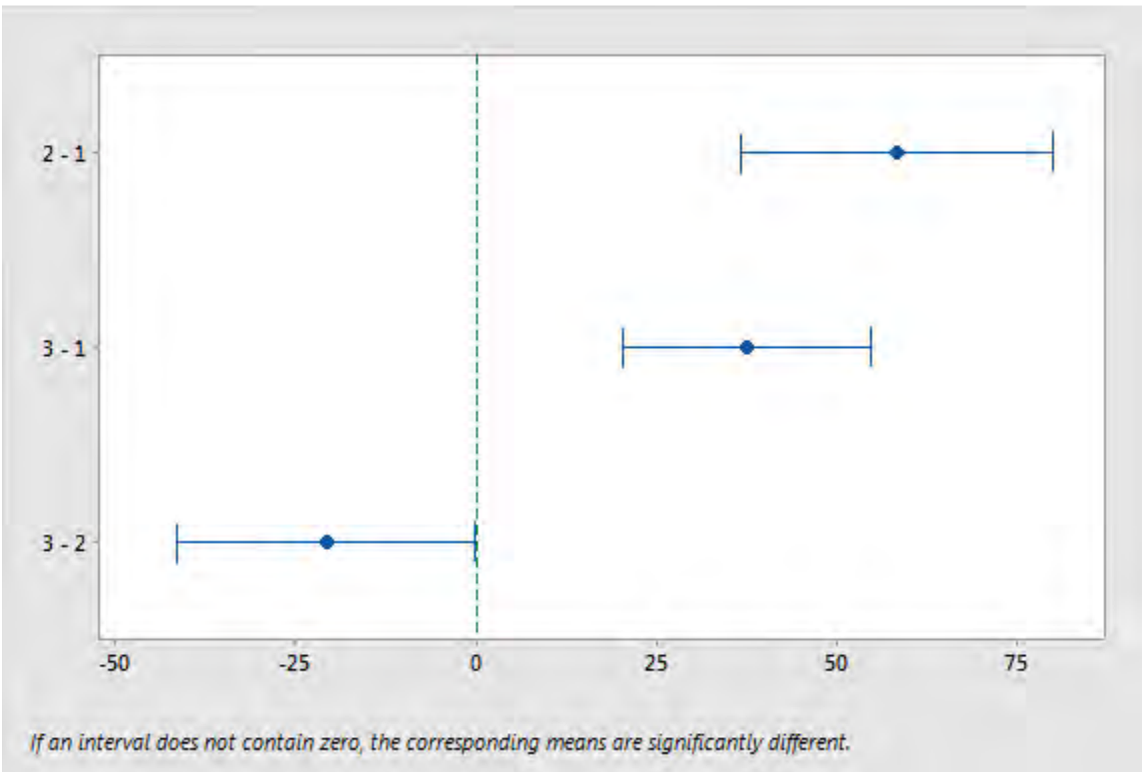

Figure 5. Simultaneous 98 Percent Confidence Intervals on Differences Among Condition Levels. Condition: 1 = Baseline, 2 = Gateway, 3 = City Post. (Rose Street-KVCC Site – Nighttime).

Westnedge Avenue at Ranney T- Intersection Site

Research Design

The data collected from the Westnedge Avenue at Ranney T-intersection site were obtained under an eight-phase time-series design that includes 37 data collection days. The eight phases are labeled as follows: (1) Baseline, (2) Edge, (3) Center, (4) Full Gateway, (5) City Post, (6) Edge, (7) Baseline, and (8) City Post.

Visual Analysis

A conventional time-series plot of the yielding data collected during each of the eight phases is presented in Figure 6. It is obvious that there are major shifts from phase to phase. Because the design has eight phases but only five conditions, some conditions have more than one phase. It may be easier to visualize the overall differences in yielding between conditions in Figure 7, because different phases belonging to a given condition are connected with lines. For example, near the bottom of Figure 7 the first and seventh phases contain the baseline data; these phases are connected with a straight line.

It is obvious that there is essentially no yielding during the baseline condition (regardless of phase) and that all other conditions have higher yielding. More specifically, it can be seen that the highest yielding is associated with the Full Gateway condition and that the data for all other conditions fall between these two extremes. It appears that the Edge and Center conditions resulted in minor to moderate improvements, and the City Post condition had a major effect, although the latter effect appears to be below that of the Full Gateway condition. Formal statistical evaluations of the effects are presented next.

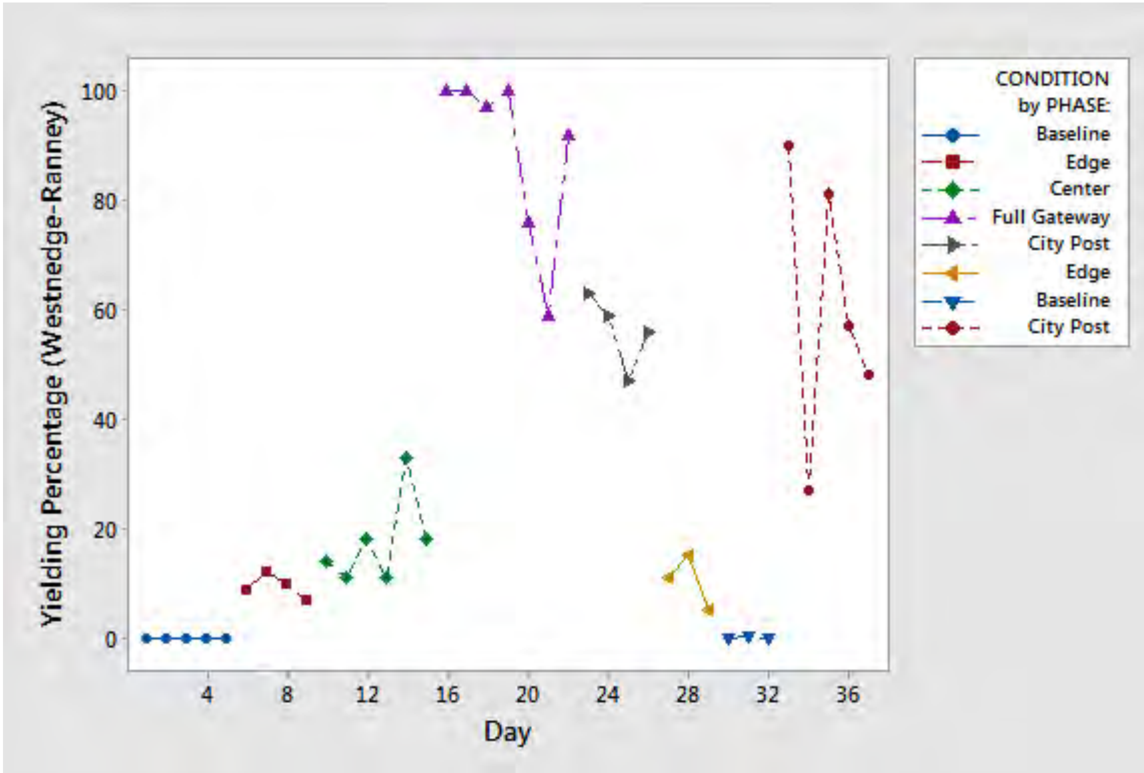

Figure 6. Yielding Percentage by Phase (Westnedge at Ranney Site).

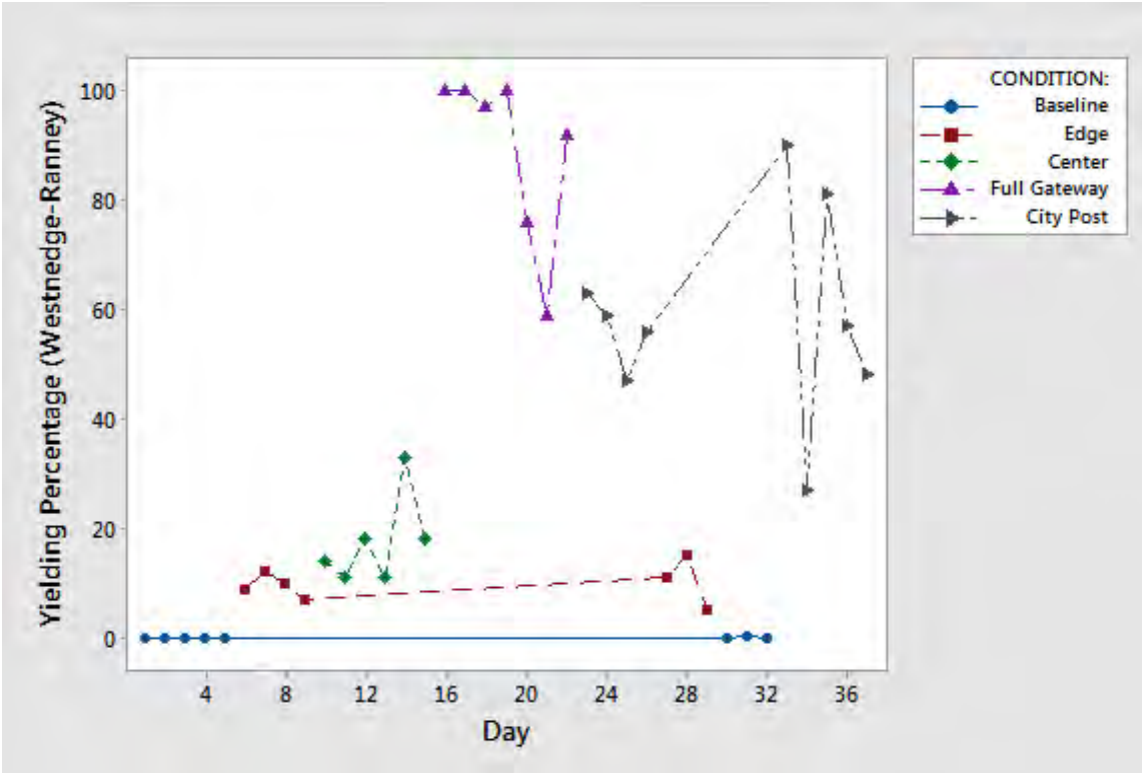

Figure 7. Yielding Percentage by Condition (Westnedge at Ranney Site).

Statistical Methods

Modeling Approach

The general modeling approach applied to the Westnedge-Ranney data is similar to the one used for the Rose Street-KVCC site analyses. That is, a complex time-series regression intervention model was initially estimated; tests were then used to determine whether simplifications were justified, and the final model was evaluated. Table 7 presents a summary of these tests and the associated results.

Table 7. Summary of Tests Used in Model Identification and Evaluation (Westnedge-Ranney Site).

1. *Model-comparison test*. The comparison of the Full Model (including level change and trend change parameters) versus the Restricted Model (including level change parameters only) yields F = 0.754 (df = 8, 21) and p = 0.65. It is concluded that within-phase trend and trend change parameters are not necessary and that the simpler (level change only) model is satisfactory.
2. *Test for homogeneous within-condition phase levels*. The test for the equality of the phase levels within conditions (F = .09, df = 3, 29, p = .98) is retained; pooling all the data within each condition is justified.
3. *Test of the assumption of independent errors*. Autocorrelation among residuals of the final analysis (a 5-condition level change model) is not present (Durbin-Watson statistic = 2.54, p > .05; H-M statistic = -.41, p = .68; Ljung-Box test for lag11 through lag-9 autocorrelation yields Q = 6.41, p-value = 0.70). Conclusion: Autoregressive parameters are not required in the model because the errors appear to be independent.
4. *Test of the assumption of a normal error distribution*. The Anderson-Darling test applied to the residuals of the 5-condition level-change model rejects the normality assumption (p-value < 0.01). Approximate normality is not present. A modified test insensitive to non-normality is indicated.
5. *Test of the assumption of homogeneous of within-condition variances*. Levene's test rejects (p < 0.05) the hypothesis of variance homogeneity. Subsequent tests comparing condition levels are modified (using rank based Welch-F and Games-Howell-q approaches) to accommodate this heterogeneity.

Model Simplification

The initial eight-phase analysis contains 16 parameters that include measures of level change and trend change from phase to phase. Tests were then carried out to determine if a simpler model is adequate for these data. First, a model comparison test (reported as the first entry in Table 7) supports a model that does not include measures of trend, because systematic trends were not present within phases. Only level-change parameters are required in the model.

Second, a test was carried out to determine whether it is appropriate to pool the data from different phases within conditions. The results of this test are presented as the second entry in Table 7. This test justifies pooling the data. Because the yielding percentages between phases within conditions are essentially the same, these phases were combined. That is, the two baseline phases were combined to form one condition. Similarly, the two Edge phases were combined to provide the overall Edge condition, and the two City Post phases were combined to provide the overall City Post condition. Hence, even though there are eight phases in the design, the model selected for the final analysis involves the comparison of only five conditions (i.e., Baseline (combined), Edge (combined), Center, Full Gateway, and City Post (combined).

Final Model

The model identified as most appropriate for these data includes five parameters. It is similar to the four-parameter model identified for the Rose-KVCC (daytime) site (described in detail earlier), but the present model includes one additional level-change parameter. The five parameters measure the initial level during baseline as well as change from condition to condition. The last three entries in Table 7 summarize tests that evaluate the adequacy of this five-parameter level-change model.

All three tests of independence retain the hypothesis of independent errors; hence, the most important assumption appears to be met. The tests for normality and homogeneity of variance conclude that these assumptions are not met. These problems occur because the Baseline-condition data are essentially constant. An alternative analysis (a rank-based approach incorporating the Welch-*F* and Games-Howell-*q* methods) that is little affected by either non-normality or heterogeneity of variances was applied to the data; it yields the same conclusions regarding the effects of the interventions as does the originally selected level-change model. For this reason, only the results of the latter are reported here.

Results

An inspection of the condition levels (Table 8) and the differences among them (Table 9) leaves no doubt that large effects were obtained. The standardized effect sizes listed in Table 9 are consistent with this conclusion. All standardized effect sizes, except the one for the Edge-Center comparison, exceed the criterion for a large effect. In addition, approximately 90 percent of the variation in the experiment (as measured by the $\hat{\eta}^2$ statistic) is explained by the interventions.

Inferential statistical tests and confidence intervals essentially eliminate the argument that either the overall results or any individual difference between condition levels may have occurred only as a result of chance. The Welch-*F* omnibus test for differences among all condition levels yields a value of 85.88 ($p < .001$). Hence, the observed differences among the three condition levels are much too large to be reasonably attributed to sampling error. The Games-Howell multiple comparison test applied to each individual pairwise difference between condition levels reveals a statistically significant ($p < .05$) effect for each of the 10 pairwise differences, except for the 7.64-point difference between the Edge and Center levels.

Correspondingly, the simultaneous 95 percent confidence intervals can be seen in Figure 8. Note that none of the intervals traps zero except the “3 – 2” contrast, which is the Center – Edge comparison. We can be 95 percent confident that the whole set of intervals trap the true difference between condition levels. Because only the Center - Edge interval traps zero it can be concluded that zero is not a credible value for the true effect in the case of any of the other nine comparisons.

Table 8. Yielding Level and Variance for Five Conditions (Westnedge-Ranney Site)

Condition	Yielding Percentage Level	Variance
1. Baseline	0.05	0.02
2. Edge	9.86	10.81
3. Center	17.50	67.50
4. Full Gateway	89.14	250.81
5. City Post	58.67	345.25

Table 9. Ten Intervention Effect Estimates, Familywise *p*-values, and Standardized Effect Sizes (Westnedge-Ranney Site).

Conditions Compared	Level Difference	Familywise *p*-value	Standardized Effect Size
Edge-Baseline	9.81	< 0.05	0.81
Center-Baseline	17.45	< 0.05	1.44
Full Gateway-Baseline	89.09	< 0.05	7.37
City Post – Baseline	58.62	< 0.05	4.85
Center – Edge	7.64	> 0.05	0.63
Full Gateway – Edge	79.28	< 0.05	6.56
City Post – Edge	48.81	< 0.05	4.04
Full Gateway-Center	71.64	< 0.05	5.93
City Post – Center	41.17	< 0.05	3.41
City Post – Full Gateway	-30.47	< 0.05	-2.52

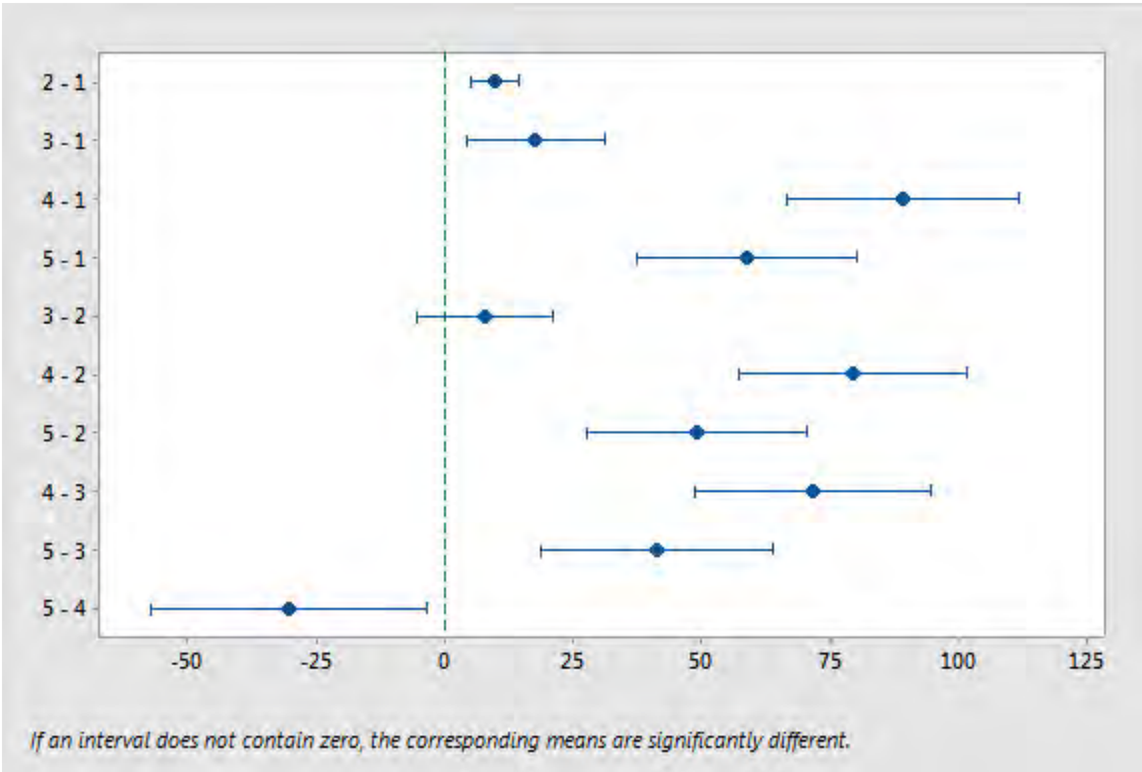

Figure 8. Simultaneous 95 Percent Confidence Intervals on the 10 Pairwise Differences Between the Five Condition Levels (Westnedge-Ranney Site). 1 = Baseline, 2 = Edge, 3 = Center, 4 = Full Gateway, and 5 = City Post.

Rose Street at Academy Site

Research Design

A 19-phase time-series research design was used at the Rose Street & Academy site. The outcome data series consists of 87 observations (daily measures of yielding). One of the following seven conditions was in effect each day: (1) Baseline, (2) Narrow, (3) Blanks, (4) City Post, (5) Wide, (6) Edge, or (7) Center.

Visual Analysis

The yielding percentage data for the Rose Street-Academy site are illustrated in Figure 9 for each of the 19 phases in this design. It can be seen that data were obtained on 87 days and the condition associated with each phase is indicated in the legend. It is somewhat cumbersome to grasp the overall outcome from inspecting this figure because there are so many phases.

The outcome may be somewhat easier to comprehend in Figure 10, which identifies all observations associated with a single condition using a line to connect the within-condition phases. Although the observations associated with the Baseline, Blanks, and City Post conditions are fairly easy to track, the data for some of the remaining conditions appear to be rather commingled.

Figure 11 presents boxplots that greatly clarify the relative standing of the outcome under the seven conditions, although these plots eliminate information regarding the time structure of the data. Each boxplot has a line running through the box that indicates the condition median. The bottom and top portions of each box can be interpreted, approximately, as the first and third quartiles of the indicated condition distribution.

Inspection of these boxplots makes it clear that the Baseline condition has the lowest yielding rate by far. The Narrow and Wide conditions appear to have the highest overall yielding percentages, but the Narrow condition appears to have a somewhat more consistent effect. Notice that the Narrow condition has less variation away from the center of the distribution than does the Wide condition (as indicated by the distance between the top and bottom of the box). The other conditions appear to have effects that are more moderate than those of the Narrow and Wide conditions, but all of them are much better than the Baseline condition. These brief descriptive results are supplemented with a more thorough statistical analysis below.

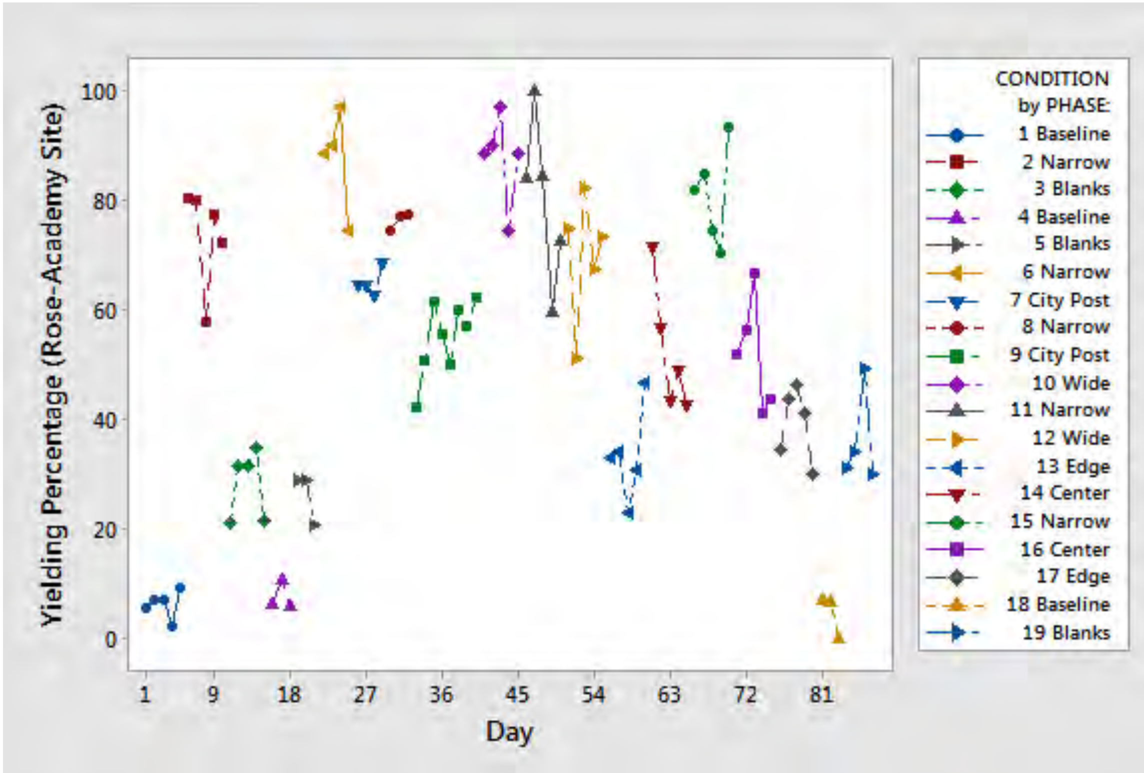

Figure 9. Yielding Percentage for 19 Phases Identified by Condition (Rose-Academy Site).

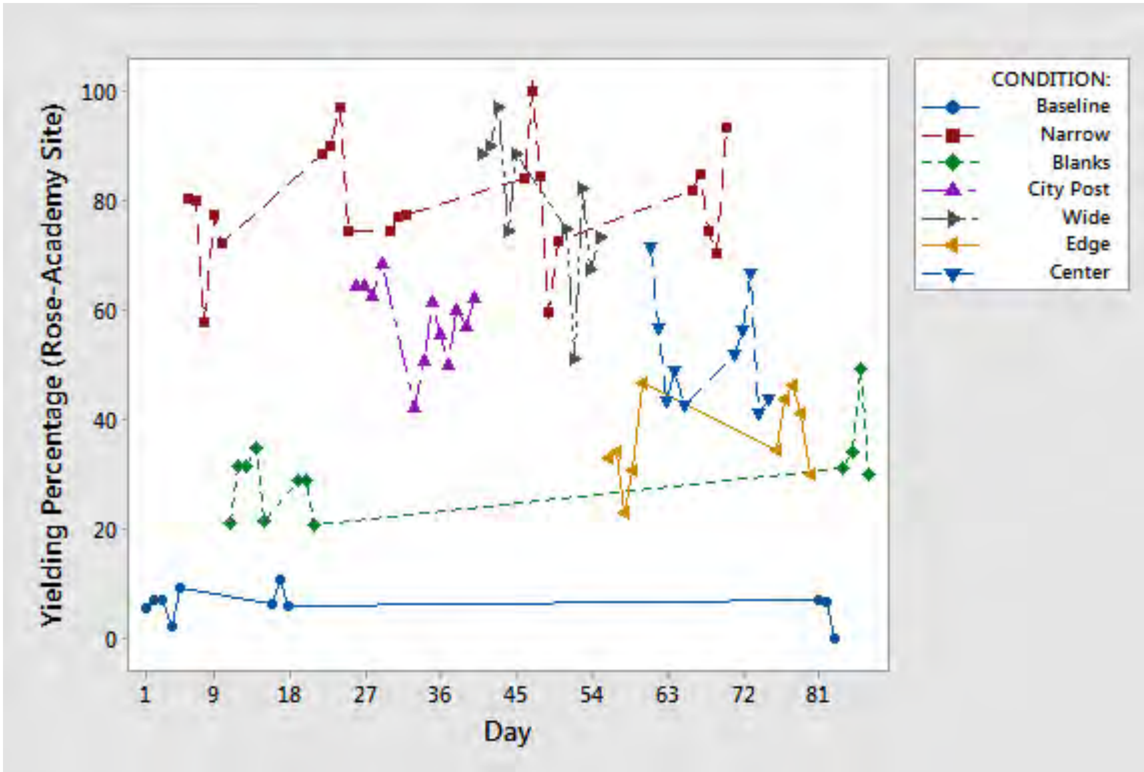

Figure 10. Yielding Percentage for Seven Conditions (Rose-Academy Site).

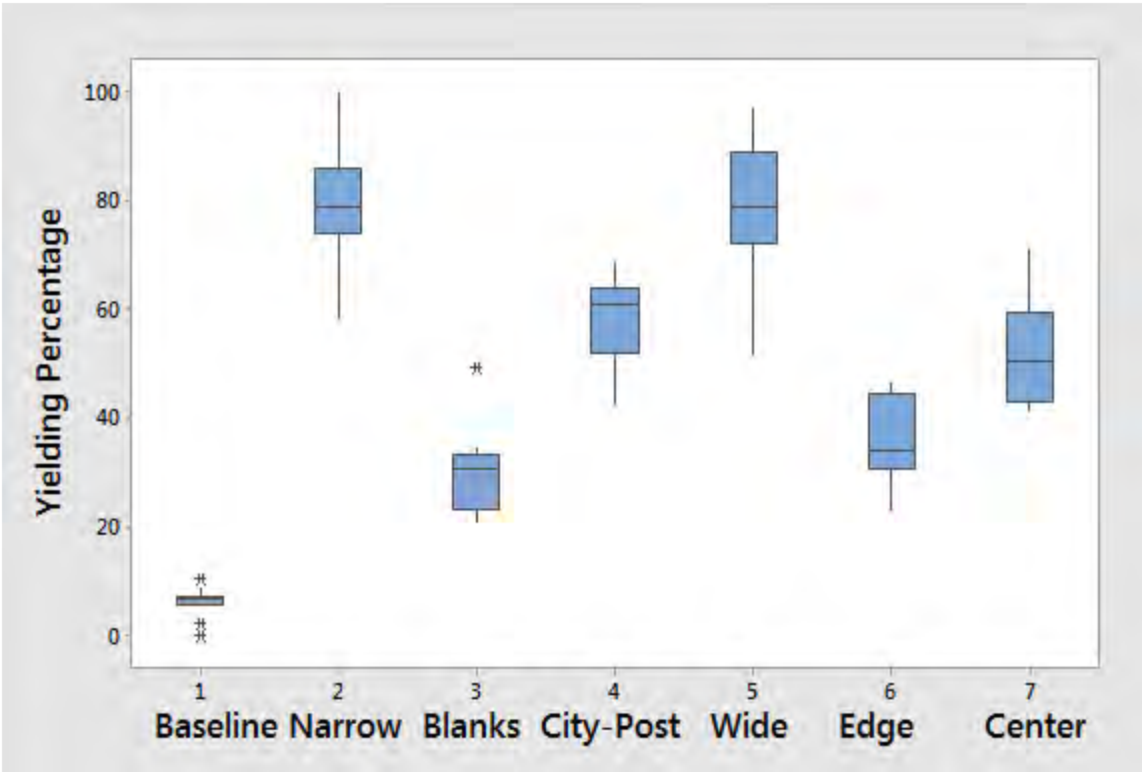

Figure 11. Yielding Percentage Boxplots for Seven Conditions (Rose-Academy Site).

Statistical Methods

Model Identification

A summary of the tests used to identify and evaluate the best model for the outcome data is presented in Table 10. The first and second entries in this table indicate that (1) there is no need for trend parameters in the model (i.e., level parameters are sufficient) and (2) the variation between phase means within each condition is small enough to justify pooling all data (from different phases) within conditions. The implications of the pooling are that the final model evaluates changes among 7 conditions rather than among 19 phases. This reduction has major descriptive and inferential advantages; among them is simplicity in the interpretation of results. There are 21 pairwise comparisons among conditions (a manageable number) whereas there are 171 pairwise comparisons among phases. Table 11 lists the specific phases included in each condition as well as the condition means.

The final model is similar to the model used for the analysis of the Rose-KVCC data, but it has seven parameters instead of four. The first parameter measures the initial Baseline level and the remaining six parameters measure change from one condition to the next and provide information needed to compare all conditions with each other.

Table 10. Summary of Tests Used in Model Identification (Rose-Academy Site)

1. *Model-comparison test*. The comparison of the Full Model (including level change and trend change parameters) versus the Restricted Model (including level change parameters only) yields $p > 0.05$. It is concluded that within-phase trend and trend change parameters are not necessary and that the simpler (level change only) model is satisfactory.
2. *Test for homogeneous within-condition phase levels*. Tests for the equality of the phase levels within conditions have Bonferroni-corrected p-values ≥ .14; the homogeneity hypothesis is retained. Pooling data from multiple phases within conditions appears justified.
3. *Test of the assumption of independent errors*. Autocorrelation among residuals of the final analysis (a 7-condition level change model) is not present (Ljung-Box test for autocorrelation based on lags-1 – 22 of the autocorrelation function yields Q = 27.38, p-value = 0.20). Conclusion: Autoregressive parameters are not required in the model because the errors appear to be approximately independent.
4. *Test of the assumption of a normal error distribution*. The Anderson-Darling test applied to the residuals of the 7-condition level change model does not reject the normality assumption (p-value = 0.24). Approximate normality is assumed.
5. *Test of the assumption of homogeneous within-condition variances*. Levene's test rejects (p = 0.03) the overall hypothesis of variance homogeneity. Consequently subsequent tests comparing the seven condition levels are modified (using Welch-*F* and Games-Howell-*q* approaches) to accommodate this heterogeneity.

Table 11. Phases Pooled Within Each of Seven Conditions and Level Estimate for Each Condition (Rose-Academy Site)

Condition	Phases Pooled Within Each Condition	Pooled Level Estimate
(1) Baseline	1, 4, 18	6.10
(2) Narrow	2, 6, 8, 11, 15	79.71
(3) Blanks	3, 5, 19	30.22
(4) City Post	7, 9	58.27
(5) Wide	10,12	78.81
(6) Edge	13, 17	36.24
(7) Center	14, 16	52.26

Final Model Evaluation

The final model was estimated and the residuals from it were used to evaluate whether the underlying model assumptions are met. Entries 3, 4, and 5 in Table 10 summarize the results of tests regarding the assumptions. Entry 3 describes the test of the assumption of independent errors; the results of the Ljung-Box test imply that no additional parameters are required to measure dependency across time. The model errors appear to be correctly specified as approximately independent. Entry 4 describes the results of the test for approximate normality of the error distribution; this assumption appears to be met. The test described in Entry 5 indicates that the assumption of homogeneous condition variances must be rejected. This test result does not invalidate the basic model or the estimation of effect estimates, but it does change the methods required to provide valid inferential results. That is, the conventional methods for estimating error variances, hypothesis tests, and confidence intervals must be modified to appropriately accommodate heterogeneous variances. Two methods were used here; they are known as the Welch-*F* omnibus test and the Games-Howell-*q* multiple comparison test.

Figure 12 illustrates several different ways of plotting the residuals of the model. These plots provide visual confirmation of the test results described above. The plot in the lower right quadrant of the figure illustrates the behavior of the residuals across time. It can be seen that, in general, the value of a residual observed on one specific day is not predictive of the value of the residual on subsequent days. This is why the Ljung-Box test for autocorrelated residuals is not statistically significant. The plots in the upper left and lower left quadrants provide descriptive information regarding the normality assumption. The upper left "normal probability" plot is used to identify departures from normality; when the dots depart little from the straight line, approximate normality is present. Because most dots shown in this plot are fairly close to the straight line it appears that approximate normality is present. The plot in the lower left quadrant, which is simply the distribution of the observed residuals, can be seen to be approximately normal. The plot in the upper right quadrant indicates the residuals for each of the seven conditions. The distance from left to right represents the yielding percentage. The distribution of dots that appear on the left of the plot are the Baseline residuals. Notice that this distribution has less variation than do the six other distributions (i.e., the non-Baseline distributions). These discrepancies represent the variance heterogeneity that is identified by Levene's test.

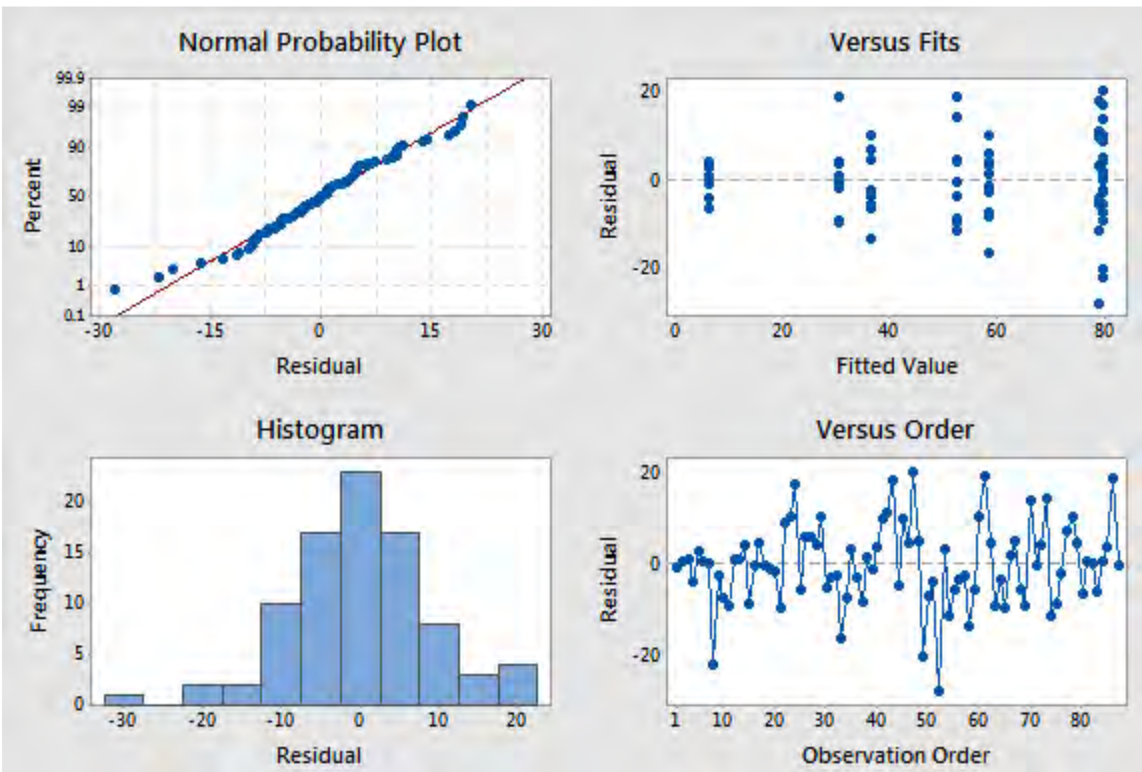

Figure 12. Residual Plots Indicating Conformity With or Departure From Assumptions of the Final Model (Rose-Academy Site).

The conclusions of the model evaluation stage are that (1) the data conform to two of the three assumptions of the final model and (2) the third assumption (homogeneity of error variances) is violated, but alternative statistical methods that accommodate this problem are appropriate for the inferential aspects of the analysis. The outcome of the study, based on the final model, is presented next.

Results

The average yielding percentage associated with each condition is shown in the second column of Table 12. The Welch-*F* omnibus test for differences among these seven means produces a value of 233.15 ($p < .001$). It can be concluded that differences among these mean estimates are far too large to be explained as sampling fluctuation. Most of the variation in the experiment is explained by between condition differences ($\hat{\eta}^2 = 0.89$). Because this evidence supports the argument that overall intervention effects exist, more specific tests (and/or confidence intervals) evaluating differences between pairs of conditions are of interest.

There are 21 pairwise comparisons in this seven-condition experiment. The two conditions associated with each comparison are listed in in the first column of Table 13. For example, the first entry in the first column is “Narrow – Baseline” and the value in the next column is 73.61; the latter is computed as the Narrow mean (79.71) minus the Baseline mean (6.10). The third column lists the *p*-value associated with the test on the difference between the two condition means, and the last column lists the standardized effect size. The standardized effect size is simply the effect estimate (i.e., the difference between condition means) divided by the pooled within-condition standard deviation (9.84). (Baseline data were not included in the computation of this pooled value because the Baseline standard deviation underestimates the error variation present in all other conditions.)

An examination of the first six rows of Table 13 reveals that each experimental condition has an average yielding percentage that is higher than the Baseline percentage by at least 24 points. The range for the size of the effects is 24.12 points for the least effect condition (Blanks) to 73.61 for the most effective (Narrow).

The order of the observed effects of the six active intervention conditions is as follows: Narrow > Wide > City Post > Center > Edge > Blanks. It should be pointed out, however, that the difference between the Narrow and Wide effects are both descriptively trivial and statistically unimportant. Similarly, both the (Blanks – Edge) and (Center - City Post) differences are well within the range of variation that can be attributed to sampling error. This can be concluded from the nonsignificant (ns) *p*-values shown in column three.

An alternative (and perhaps more transparent) analysis of the same data can be seen as the set of confidence intervals presented in Figure 13. There are 21 intervals in this figure. These intervals are presented in exactly the same order (from top to bottom) as the test results shown

Table 13. Notice that three confidence intervals trap zero. These are the confidence intervals associated with the (Narrow – Wide), (Blanks – Edge), and (Center – City Post) differences. When an interval contains zero this means that zero is a credible value for the true difference between condition means.

Just as 18 of the 21 familywise *p*-values in Table 13 are less than 0.05 (and therefore are declared statistically significant), 18 of the confidence intervals in Figure 13 do not trap zero. Both approaches lead to the conclusion that these 18 differences are too large to be explained by sampling error. The advantages of the confidence interval approach are that (1) the degree to which an interval deviates from zero can be observed directly and (2) the width of the interval provides a clear indication of the amount of uncertainty associated with the mean difference estimate.

The intervals provided in Figure 13 are called "simultaneous 95 percent confidence intervals" because the probability is 0.95 that the whole set of 21 intervals contain the true differences. Because this probability value refers to the whole set of intervals, the degree of confidence that an individual interval traps the true value is actually much higher than .95.

Table 12. Yielding Level and Variance for Seven Conditions (Rose-Academy Site)

Condition	**Mean Yielding Percentage**	**Variance**
1. Baseline	6.10	8.40
2. Narrow	79.71	111.05
3. Blanks	30.22	59.00
4. City Post	58.27	56.70
5. Wide	78.80	180.59
6. Edge	36.24	61.65
7. Center	52.26	110.50

Table 13. Intervention Effect Estimates, Familywise *p*-values, and Standardized Effect Sizes for 21 Pairwise Condition Comparisons (Rose-Academy Site)

Conditions Compared	**Difference Between Means**	**Familywise *p*-value**	**Standardized Effect Size**
Narrow - Baseline	73.61	< 0.05	7.48
Blanks – Baseline	24.12	< 0.05	2.45
City Post - Baseline	52.17	< 0.05	5.30
Wide – Baseline	72.70	< 0.05	7.39
Edge - Baseline	30.14	< 0.05	3.06
Center – Baseline	46.16	< 0.05	4.69
Blanks – Narrow	-49.49	< 0.05	-5.03
City Post – Narrow	-21.44	< 0.05	-2.18
Wide – Narrow	-0.91	> 0.05 (ns)	-0.09
Edge – Narrow	-43.47	< 0.05	-4.42
Center – Narrow	-27.45	< 0.05	-2.78
City Post - Blanks	28.05	< 0.05	2.85
Wide – Blanks	48.58	< 0.05	4.94
Edge – Blanks	6.02	> 0.05 (ns)	0.62
Center – Blanks	22.04	< 0.05	2.24
Wide – City Post	20.53	< 0.05	2.09
Edge – City Post	-22.03	< 0.05	-2.24
Center – City Post	-6.01	> 0.05 (ns)	-0.61
Edge – Wide	-42.56	< 0.05	-4.32
Center – Wide	-26.54	< 0.05	-2.70
Center - Edge	16.02	< 0.05	1.63

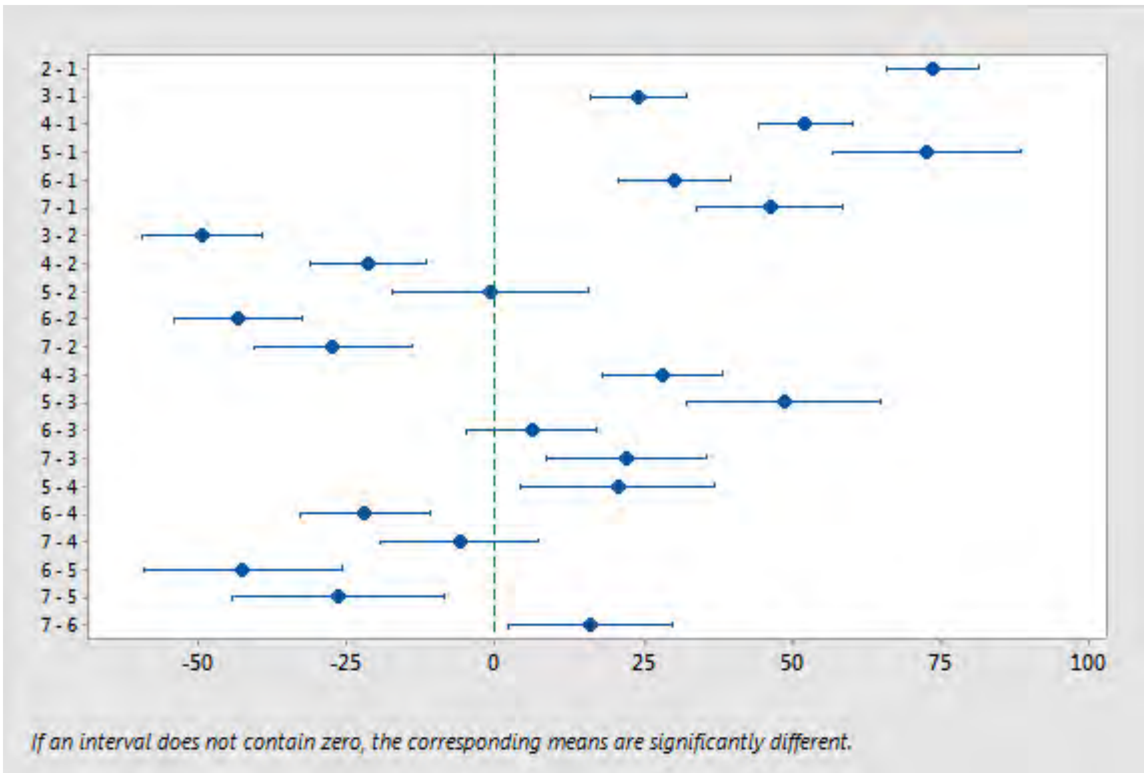

Figure 13. Simultaneous 95 Percent Confidence Intervals for 21 Pairwise Differences Between Seven Condition Means (Rose-Academy Site).

The standardized effect sizes listed in the final column of Table 13 for the first six rows argue that the effects of the intervention conditions are of practical importance. Each of the six values easily exceeds the conventional criterion (viz., 0.80) for defining a "large" treatment effect.

More importantly, even the least effective intervention (Blanks) has a yielding percentage that is five times the size of the Baseline percentage, and the two most effective interventions (Narrow and Wide) have yielding percentages that are approximately 13 times the Baseline percentage. Regardless of the statistical measure used to evaluate the size or importance of the outcome the conclusion is the same: large effects are demonstrated in this experiment.

Also, the last 15 rows in the last column of Table 13 indicate that all comparisons among the active (i.e., non-Baseline) intervention conditions except the previously mentioned (Wide-Narrow), (Edge-Blanks), and (Center-City Post) comparisons are statistically significant and greatly exceed the criterion for a large effect.