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EFFECTIVENESS OF RECTANGULAR RAPID FLASHING BEACONS (RRFBs) IN SMALL AND RURAL COMMUNITIES

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Effectiveness of Rectangular Rapid Flashing Beacons (RRFBs) in Small and Rural Communities

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THE UNIVERSITY OF VERMONT
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16. Abstract
Ensuring the safety of pedestrians and cyclists in rural and small communities is becoming increasingly important as planners seek to encourage active travel and eliminate traffic-related injuries and fatalities, consistent with Vision Zero. One area of focus is the protection of vulnerable road users such as pedestrians, who face a significant risk of injury or death in a traffic collision. The risks to pedestrians are particularly high when crossing roadways in high-risk areas such as high-speed and low pedestrian-volume rural roads and between intersections where drivers may not expect them. One concern in rural communities is that pedestrians may face a heightened risk in rural transition zones as they approach the boundary of a city, town, or village from a higher-speed rural highway. In these settings drivers' perceptions may lag behind their changing surroundings, and their awareness of reduced speed limits and the presence of pedestrians may be diminished.

This report addresses the need to evaluate the effectiveness of RRFBs in rural and small communities. We first review prior literature on RRFB effectiveness to synthesize research insights that provide context-specific guidance for their use as well as gaps in this literature. To supplement this body of research, we use a rigorous observational research design to evaluate the effectiveness of RRFBs within the unique context of small and rural communities in Vermont. Our results are used to provide recommendations for updating Vermont's RRFB guidelines.

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About the Transportation Research Center

The Transportation Research Center at the University of Vermont (UVM TRC) conducts research that advances the science of understanding how we travel, the design of resilient transportation systems, and the impact of transportation on the environment, our health and wellbeing, and the economic prosperity of diverse communities. The UVM TRC has a unique focus on understanding the transportation challenges of people and businesses in small municipalities and rural communities to provide local and state government decision makers with practical, research-informed insights to support more sustainable, equitable, and resilient transportation systems that serve the needs of all individuals and communities.

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EXECUTIVE SUMMARY

Ensuring the safety of pedestrians and cyclists in rural and small communities is becoming increasingly important as planners seek to encourage active travel and eliminate traffic-related injuries and fatalities, consistent with Vision Zero. One area of focus is the protection of vulnerable road users such as pedestrians, who face a significant risk of injury or death in a traffic collision. The risks to pedestrians are particularly high when crossing roadways in high-risk areas such as high-speed and low pedestrian-volume rural roads and between intersections where drivers may not expect them. One concern in rural communities is that pedestrians may face a heightened risk in rural transition zones as they approach the boundary of a city, town, or village from a higher-speed rural highway. In these settings drivers' perceptions may lag behind their changing surroundings, and their awareness of reduced speed limits and the presence of pedestrians may be diminished.

One way to reduce the safety risks faced by pedestrians is to improve the safety of pedestrian crossings. An increasingly common pedestrian crossing treatment is Rectangular Rapid Flashing Beacons (RRFBs), designed to increase drivers' awareness of pedestrians using a pedestrian-activated beacon. These beacons are typically used with other treatments such as marked crosswalks and advanced yield markings, median signs or speed limit reductions. However, evaluations of the effectiveness of RRFBs to date have largely occurred in urban contexts, leaving planners in rural communities with little guidance for their use. One risk is that RRFBs may cause pedestrians to feel emboldened, even as drivers fail to register their presence in rural contexts or in rural transition zones.

This report addresses the need to evaluate the effectiveness of RRFBs in rural and small communities. We first review prior literature on RRFB effectiveness to synthesize research insights that provide context-specific guidance for their use as well as gaps in this literature. To supplement this body of research, we use a rigorous observational research design to evaluate the effectiveness of RRFBs within the unique context of small and rural communities in Vermont. Our results are used to provide recommendations for updating Vermont's RRFB guidelines.

PRIOR RESEARCH ON RRFB EFFECTIVENESS

Pedestrian safety depends on several contextual factors, such as the presence of sidewalks, vehicle and pedestrian volume, demographics of the area and pedestrians, number of lanes, and vehicle operating speed. When evaluating RRFBs, prior research indicates that they improve drivers' yielding behavior, reduce conflicts between pedestrians and vehicles, and reduce crash severity, even as they may reduce pedestrians' looking behavior when crossing.

However, RRFB effectiveness is also known to vary across locations, although little is known about the contextual factors that lead to those differences in effectiveness. It is important to evaluate RRFBs applicability across contexts to ensure that they are used effectively, particularly when considering installing RRFBs in contexts that differ substantially from those where most prior studies have occurred.

One limitation of this body of research is that evaluations of RRFB effectiveness in rural-specific contexts are limited, as prior RRFB research has largely been conducted in urban and suburban areas. This is the case despite literature that indicates that rural crashes are more likely to result in a fatality and drivers are less likely to expect pedestrians in rural areas. Prior studies also have not explicitly evaluated the effect of the built environment (such as density of surroundings) on RRFB effectiveness, which could point to differences that might apply in rural communities. Additionally, no study has focused on the effectiveness of RRFBs in rural transition zones, where drivers' perception of the speed limit and pedestrian activity may be diminished as they approach the boundary of a city or town from a higher speed rural highway. Finally, most RRFB evaluation studies lack a "control" comparison or evaluate cross-sectional differences in pedestrian risks by comparing the outcomes of RRFBs versus non-RRFB crossings, limiting their ability to demonstrate causal effects.

RRFB Effectiveness in Vermont's Small and Rural Communities

This study addresses the gap in our understanding of the extent to which RRFBs improve pedestrian safety in rural contexts. Specifically, we answer the following two questions:

1. Are RRFBs effective in Vermont's small and rural communities?
2. Are RRFBs effective in town centers as well as in rural transition zones?

We use a robust before and after controlled design to evaluate these two research questions in the Vermont context. We evaluate RRFB effectiveness in terms of outcomes that represent driver and pedestrian compliance as well as risky behaviors and conflicts that serve as a proxy for safety. We evaluate these outcomes at six locations where RRFBs or similar devices are newly installed. Each location is paired with a similar control location that has a crossing (either an RRFB or a traditional crosswalk) that did not change over the study period. Each pair is observed simultaneously using video recordings before and after installing the treatment location's RRFB. The pair serves as a control location to ensure that our analysis isolates observed changes directly related to the RRFB installation. We use rigorous content analysis techniques to code variables and outcomes observed in video recordings to ensure that our data are robust.

We then evaluate the effectiveness of RRFBs in the Vermont context in two ways. We first summarize the difference-in-difference (DID) observed (before and after and between pairs). This provides a relatively simple comparison of the difference in the change in outcomes where RRFBs are installed relative to a similar location where no change in the crossing occurred. The results are robust for cases where time-varying changes are relatively consistent at both the RRFB and the control location, so that confounding factors (such as weather or pedestrian characteristics) do not bias the results. We also use multivariate regression analysis of before and after data, allowing us to evaluate differences in outcomes while explicitly controlling for confounding factors.

Overall, we find that installing RRFBs in small and rural locations leads to compliance and safety improvements including increasing driver yielding and the rate pedestrians crossing out-of-crosswalk. They may also improve pedestrian wait times and the rate with which drivers stop suddenly. We find mixed results for driver stopping position and the rate at which pedestrians step into the roadway before drivers yield.

We also find suggestive evidence that RRFB installations are likely to be beneficial in both central and rural transition zone locations, although their effectiveness may be reduced if they diverge significantly from applicable design guidelines. Two sites that were planned as RRFBs were built as pedestrian-activated signs that use LED embedded pedestrian crossing signs instead of rectangular beacons specified for RRFBs. These two sites performed worse than the RRFB installations in our study.

Recommended updates to Vermont's RRFB installation guidelines

Based on the findings from the literature review and our observations of the effectiveness of RRFBs in the Vermont context, we make several recommendations for updating the 2019 *VTrans Guidelines for Pedestrian Crossing Treatments*. We suggest expanding the range of roadway types considered for RRFB installation, emphasizing RRFB design features that are not always used in practice, and supplementing the considerations for the types of users and concerns that merit consideration for RRFBs.

1.0 INTRODUCTION

Ensuring the safety of pedestrians and cyclists in small and rural communities is becoming increasingly important as planners in these communities seek to eliminate traffic fatalities and support active travel. Pedestrians are among the most vulnerable roadway users, facing significant risks of injury or death in a traffic collision, particularly when crossing roadways. Over 35,000 traffic fatalities were reported in the US in 2019, 17% of which were pedestrian fatalities. In the same year, more than 76,000 pedestrians were injured nationwide (NHTSA, 2020). Safety risks are of particular concern in rural areas, where crashes are more likely to result in a fatality (Ivan et al., 2001). The heightened risk in rural communities is stark, with 8% of US walk trips and miles walked occurring in rural areas in 2017, while 19% of pedestrian deaths occurred in rural areas in the same year (IIHS, 2020).

Pedestrian safety studies have identified several factors that contribute to pedestrian crashes, including driver skills, vehicle speed, road design, pedestrian distraction, and demographics (Zegeer & Bushell, 2012). In addition, it is widely accepted that crossing safety is context-specific and is influenced by built environment characteristics in both urban and rural areas (Duddu et al., 2017; Effati & Vahedi Saheli, 2022).

One approach to increasing pedestrian safety is to improve the design of facilities where pedestrians and vehicles face potential conflicts. An increasingly popular pedestrian crossing treatment is Rectangular Rapid Flashing Beacons (RRFBs), designed to increase drivers' awareness of pedestrians using a pedestrian-activated signal. Overall, prior research has indicated that RRFBs improve drivers' yielding behavior, reduce conflicts between pedestrians and vehicles, and reduce crash severity, even as they may adversely affect pedestrians' looking behavior when crossing (Al-Kaisy et al., 2018; Brewer et al., 2015; Dougald, 2016; Fitzpatrick et al., 2014; Monsere & Figliozzi, 2016; Potts et al., 2015b).

However, RRFB effectiveness varies across locations (Fitzpatrick et al., 2014; Fitzpatrick, Potts, et al., 2015; Potts et al., 2015a), and identifying suitable sites for RRFB installation is challenging because little is known about the contextual factors that lead to those differences in effectiveness. It is important to evaluate RRFBs' applicability across contexts to ensure that they are used appropriately, particularly when considering installing RRFBs in contexts that differ substantially from those where most prior studies have occurred.

It is well understood that the surrounding built environment and land use influence pedestrian activity (Miranda-Moreno et al., 2011; Vale & Pereira, 2016), which may in turn, influence driver yielding and pedestrian crossing behavior. For example, drivers may be conditioned to notice pedestrians in urban areas more than in rural areas, and pedestrians expecting this conditioning may be emboldened to cross more aggressively. Similarly, pedestrians may face greater risks in transition zones, where drivers approach the boundary of a village or town center from a higher-speed rural highway. In these settings, drivers' expectations may lag behind their changing surroundings, and their awareness of reduced speed limits and the presence of pedestrians may be diminished.

Practitioners have expressed concern that RRFBs may cause pedestrians to feel overconfident when crossing, and drivers may fail to register their presence in rural contexts or in transition zones. However, prior studies on the effectiveness of RRFBs have not explicitly evaluated the effect of the built environment on RRFB effectiveness and have not sufficiently evaluated their performance in rural contexts and rural transition zones. There is a need to address this gap to inform the design of safe pedestrian crossings in these contexts. Robust information about the benefits of installing these treatments in rural areas and transition zones, where drivers may be less alert to the presence of pedestrians, can be used to determine when their use is merited in these communities.

This study evaluates the effectiveness of RRFBs in small and rural community contexts. We first review prior literature on RRFB effectiveness to synthesize context-specific guidance for its use. We then use a rigorous observational research design to extend this prior knowledge by evaluating the effectiveness of RRFBs in the context of small and rural communities in Vermont. Our analysis focuses on the extent to which RRFBs are effective in the Vermont context. We also evaluate whether RRFBs are effective in both central and rural transition zone contexts in Vermont communities. Finally, we close with recommendations for updating Vermont's RRFB guidelines.

2.0 PRIOR RESEARCH ON RRFB EFFECTIVENESS

As transportation agencies move toward the goal of eliminating traffic fatalities, there is a growing focus on improving the safety of vulnerable road users such as cyclists and pedestrians. Improving cyclist and pedestrian safety can also encourage active transportation.

Pedestrian safety depends on several factors, such as the presence of sidewalks, vehicle and pedestrian volume, driver and pedestrian demographics, number of lanes being crossed, and driver operating speed (Miranda-Moreno et al., 2011). Although most pedestrian crashes and fatalities occur in denser urban areas, rural crashes are more likely to result in fatalities (Ivan et al., 2001). One reason for the increased lethality is that drivers tend not to expect pedestrians in rural areas (Coogan et al., 2011). Another reason is that non-intersection crossing is more frequent in rural areas because blocks are much longer, and intersections are less frequent (FHWA, 2006).

Several types of crossing treatments are designed to make crossings safer and reduce pedestrian-driver conflicts, including medians and refuge islands, pavement markings, staggered midblock crosswalks, grade-separated crossings, and unique signaling for pedestrians (Porter et al., 2016). The effectiveness of these treatments varies, is context-specific, and depends on driver and pedestrian behavior. However, in some cases, crossing treatments perform similarly across contexts. For example, Mitman et al. (2010) investigated driver and pedestrian behavior at uncontrolled crosswalks in rural and small municipal locations in California's Lake Tahoe basin. They compared these small and rural locations to urban and suburban locations in the San Francisco area. In addition, they compared marked and unmarked pedestrian treatments in both urban and rural areas. The performance of marked and unmarked crosswalks was relatively similar across urban/suburban and rural/recreational contexts included in the study, suggesting that in this case pedestrian crossing recommendations in rural areas can follow urban areas (Mitman et al., 2010).

The Rectangular Rapid Flashing Beacon (RRFB) is a relatively recent crossing treatment. RRFBs are similar to traditional marked crosswalks except that they allow pedestrians to press a button to activate bright flashing lights attached to the crosswalk sign. RRFBs are designed to improve pedestrian safety by providing extra emphasis on marked crosswalks by attracting drivers' attention from a greater distance and alerting them to the presence of a waiting pedestrian, giving drivers a longer response time. Early RRFB pilot projects indicated that RRFBs improve pedestrian safety compared with similar crosswalks without RRFBs (Hunter et al., 2012; Shurbutt & Van Houten, 2010). As a result, the Federal Highway Administration (FHWA) issued interim approval for RRFBs in 2008 (FHWA, 2008). The approval was updated in 2018 with a research summary and design guidelines, allowing agencies to install RRFBs where they find it warranted (FHWA, 2018).

Earlier studies of RRFBs largely focused on improving RRFB design, for example establishing effective flashing patterns and position at curbs (Avelar et al., 2015; Brewer & Fitzpatrick, 2012; Fitzpatrick, Avelar, et al., 2015; Fitzpatrick et al., 2016; Ross et al., 2011; Shurbutt & Van Houten, 2010; Van Houten et al., 2008). Since the interim approval was issued in 2018, the focus of RRFB research has increasingly shifted to the effects of RRFBs, evaluating measures of yielding performance, driver compliance, pedestrian crossing behavior, conflicts between drivers and pedestrians, change in pedestrian volume, and crash severity at RRFB locations.

Table 1 summarizes RRFB evaluation studies that provide insight about their effectiveness relative to a traditional crosswalk (or similar) by using methods such as a before and after evaluation, comparison to control locations, or comparison of performance when RRFB is activated versus not activated. For each reference, the table summarizes the research design, reports the outcomes evaluated, and describes the contexts evaluated. For each outcome evaluated, the table also summarizes the effect of RRFBs on the outcome as well as the effect of other factors (such as vehicle type or pedestrian waiting position) on the outcome. RRFB evaluation studies that did not include a relevant comparison (e.g. evaluated yielding rate at only RRFB locations) are not described in detail here (Anderson, 2020; B. Schroeder, K. Salamati, N. Rouphail, 2015; Kutela & Teng, 2019; Moshahedi et al., 2018; Rista & Fitzpatrick, 2020).

This body of work generally indicates that RRFBs effectively improve drivers' yielding rate (Al-Kaisy et al., 2018; Brewer et al., 2015; Dougald, 2016; Fitzpatrick et al., 2014; Potts et al., 2015b). In one before and after study the yielding rate increased by an average of 80% when RRFBs were installed, with far-side yielding (from the side of the road across from the pedestrian's waiting position) improving more than nearside (Brewer et al., 2015). Another before and after study found that the average driver yielding rate for crossings with RRFBs is 86%, reflecting a 31% to 79% improvement compared with pre-installation rates (Fitzpatrick et al., 2014). In contrast, an unusually robust study that used a controlled before and after study design did not find that RRFBs had a significant effect on yielding rate, although this may be attributable to how the statistical model used to evaluate yielding was specified[1] (Porter et al., 2016). Another study found that cities with more RRFBs had higher driver yielding rates (Fitzpatrick et al., 2014), suggesting a potential benefit of familiarity with the use of RRFBs.

Evaluating driver yielding is a common approach to evaluating the effectiveness of pedestrian crossing treatments. However, simulations of crashes at 38 locations in Minnesota indicate that although yielding rate may be an indicator of driver behavior, it may be limited in its ability to serve as a safety surrogate (Hourdos, 2020). As observed in field studies, this may be because a driver's yielding to a pedestrian may not be the same behavior as a driver attempting to stop during a vehicle-pedestrian conflict such as maneuvering to avoid a pedestrian or stopping suddenly. Importantly, in addition to improving driver yielding rates, RRFBs have also been shown to reduce crash severity (Monsere & Figliozzi, 2016) as well as reducing risky interactions between pedestrians and drivers such as conflicts with right-turning vehicles and evasive actions (Fitzpatrick et al., 2014).

A smaller share of RRFB studies have investigated their impact on pedestrian crossing behaviors, such as the choice to activate the beacon or pedestrians' looking behavior. One study found that during peak hours, pedestrians are more likely to activate RRFBs while waiting to cross (Al-Kaisy et al., 2018), which may be related to the higher traffic levels during peak hours and difficulty identifying gaps in traffic to cross the roadway. Another study found that once RRFBs were installed, almost 94% of the pedestrians activated the RRFB and pedestrian crossing volumes increased by 5 to 20% (Brewer et al., 2015). In terms of effects of RRFBs on the rate at which pedestrians look before crossing, one study found that RRFBs reduce the rate of pedestrian looking (Brewer et al., 2015), while another found no significant effect (Porter et al., 2016).

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[1] The model of yielding rate included a pedestrian's waiting position as a control variable, which may change with the installation of an RRFB. This poses a potential endogeneity problem.

Table 1. Summary of select RRFB evaluation literature

Study	Research design	Outcome	RRFB effect[1]	Other factors[2]	Context evaluated
Porter et al., 2016	• Controlled before and after (RRFB vs simple crosswalk) • Logistic regression	Yield rate	RRFB (NS)	• Passenger vehicle vs. other vehicles (+) • Median (+) • Pedestrian waiting position on sidewalk vs. crosswalk (+) • Time (+)	Urban/suburban locations included but are not controlled for or evaluated
		Pedestrian looking	RRFB (NS)	• Pedestrian stopping at curb (+) • Male (+) • Number of pedestrians waiting (-) • Vehicle volume (-) • Pedestrian volume (-) • Crosswalk width (+) • Time (mixed)	
Potts et al., 2015b	• Cross-sectional (RRFB activated vs not activated) • Staged and non-staged pedestrians	Yield rate	RRFB activated (+)	• Vehicle volume (NS)	Urban/suburban locations included. Analysis controls for the location (municipality) but urban/suburban context is not explicitly controlled for or evaluated
Al-Kaisy et al., 2018	• Cross-sectional (RRFB activated vs not activated) • Video recordings	Yield rate	RRFB activated (+)	• Waiting at curb (+) • Children or elderly crossing (+) • Number of crosswalk users (+) • Bikers (+)	Urban/suburban locations included but are not controlled for or evaluated
		RRFB activation		• Peak periods (+)	
Monsere & Figliozzi, 2016	• Before and after • Crash data • Video recordings • Descriptive statistics and risk ratio	Pedestrian crash severity	RRFB (-) (improved)	• Number of lanes (+) • Posted speed (+) • Estimated pedestrian volume (+)	Urban/suburban/rural locations included but are not controlled for or evaluated

Study	Research design	Outcome	RRFB effect[1]	Other factors[2]	Context evaluated
Brewer et al., 2015	• Before-after • Staged and nonstaged video recordings • No multivariate modeling	Yielding rate	RRFB (+)	• Pedestrian waiting at the curb vs other locations (+)	Rural/suburban locations included but are not controlled for or evaluated
		Pedestrian use of the crosswalk	RRFB (+)		
		Pedestrian looking	RRFB (-)		
Dougald, 2016	• Longitudinal cross-sectional study	RRFB activation rate		• Time (+) • Traffic volume (+)	Urban locations included.
		Yield rate	RRFB activated (+)		
Fitzpatrick et al., 2014	• Before-after • Staged video recordings • Multivariate modeling of yield rate only	Yield rate	RRFB (+)	• Posted speed limit (+) • Crossing distance (-) • Time since installation (NS) • Two-way road compared to one way (-)	Urban/suburban locations included. Analysis controls for the location (municipality) but urban/suburban context is not explicitly controlled for or evaluated
		Pedestrian trapped in the roadway	RRFB (-) (improved)		
		Pedestrian-vehicle conflicts	RRFB (-) (improved)		

1. RRFB effectiveness indicates whether the installation is associated with the outcome evaluated. These relationships are reported as "NS" if not significant. If they are significant, the direction of the relationships is reported as "+" when associated with significantly higher values of the outcome variable and "-" when associated with significantly lower values of the outcome variable.
2. Other factors that relate to the outcome of interest were evaluated as control variables in many studies. These relationships are reported as "NS" if not significant. If they are significant, the direction of the relationships is reported as "+" when associated with significantly higher values of the outcome variable and "-" when associated with significantly lower values of the outcome variable. For example, "median island (+)" indicates that the presence of median islands is positively associated with the outcome evaluated. For attributes that are listed relative to another attribute, the "+" or "-" refers to the effect of the first attribute relative to the second attribute. For example, "pedestrian waiting position on sidewalk versus crosswalk (+)" indicates that the outcome is higher when the pedestrian waits on the sidewalk than on the crosswalk.

Responses to RRFBs change over time after they are installed, likely due to the increased familiarity of pedestrians and drivers in the area. One study found that as more time passes after installation, pedestrians are more likely to activate RRFBs and motorists are more likely to yield when the RRFB is activated (Dougald, 2016). Another study found that pedestrians' perceptions of safety increased with RRFB installation (Porter et al., 2016).

Not surprisingly, measured outcomes also vary across locations. Several evaluation studies included control variables for location-specific differences, with significant effects demonstrated for the city in which an RRFB is located. This is likely explained by the different contexts in each city. Contextual factors are also related to outcomes of interest in the RRFB literature. For example, the presence of a median and higher posted speed limits is related to greater rates of driver yielding (Fitzpatrick et al., 2014; Porter et al., 2016). Greater crossing distances are also associated with lower driver yield rates, although the effect size is small (Fitzpatrick et al., 2014). At the same time, higher pedestrian and vehicle volumes are related to lower rates of pedestrians looking (Porter et al., 2016) and crash severity is worse at crossings with more lanes, higher posted speeds, and higher estimated pedestrian volumes (Monsere & Figliozzi, 2016). These relationships may indicate the relative safety risks for facilities in different locations.

Notably, the study locations included in this body of RRFB research to date has included a range of contextual characteristics such as the number of lanes crossed, travel speeds, and traffic volumes, with relatively consistent findings of RRFB effectiveness. However, little is known about how contextual characteristics may (or may not) relate to differences in RRFB effectiveness across locations, which would provide additional insight into where to implement RRFB crossing treatments. For example, although we know that the presence of a median improves driver yielding, we do not know if RRFBs improve outcomes more, the same, or less in the presence of a median when compared with locations without a median. Only one controlled study has sought to evaluate differences in the effectiveness of RRFBs across different contexts by evaluating the effectiveness of RRFBs in areas with different pedestrian volumes and speed limits. However, a lack of sufficient comparison data along those dimensions does not support inferences about the effects of the combination of the RRFB and different pedestrian volumes or speeds (Monsere & Figliozzi, 2016).

Additionally, despite the complex interrelationships between pedestrian safety and rural context highlighted in other areas of safety research, no controlled study to date has focused on the differences in RRFB effectiveness between rural and urban areas. Several studies, most of which are uncontrolled, include some rural RRFB locations in their research, although they do not specifically evaluate differences in performance across urban and rural settings (Coogan et al., 2011; Hourdos, 2020; Lindsey & Investigator, 2020; Mitman et al., 2010; Monsere & Figliozzi, 2016; Ogle Jennifer, et al., 2020).

One concern in rural contexts is that RRFBs may increase pedestrian assertiveness without sufficiently increasing driver alertness, thereby making safety outcomes worse. This concern is particularly heightened in rural transition zones where drivers' perceptions of their surroundings may lag behind changes in their surroundings, potentially leading to both higher speeds and lower awareness of pedestrian activity than would be expected in urban areas. These concerns highlight the need for a better understanding of the effects of RRFBs on driver and pedestrian behaviors in small and rural communities, as well as in rural transition zones.

Finally, we note that an important limitation of RRFB research to date is that much of it relies on relatively weak research designs. Many RRFB studies lack a comparison to a "control" (whether it is a before condition, a traditional crosswalk, or an observation of RRFBs with and without activation). Without a "control" comparison, it is impossible to determine whether the observed outcomes result from the RRFB or other contextual factors. And while those that include control locations are more informative than those that do not, controlled studies that only evaluate cross-sectional differences in pedestrian risks by comparing the outcomes of RRFBs versus non-RRFB crossings are limited in their ability to demonstrate causal effects. A cross-sectional research design cannot determine whether the RRFB installation caused the observed difference in safety outcomes because it cannot control for all causal factors. If, for example, RRFBs tend to be installed at intersections that are inherently riskier, a cross-sectional analysis may erroneously indicate that RRFBs reduce safety. In contrast, if crossings with higher pedestrian volumes are more likely to be sites where RRFBs are installed and they are also more likely to be safe because drivers already have greater awareness of pedestrians, then a cross-sectional research design will erroneously indicate that RRFBs increase safety.

In this review of prior work we have focused primarily on studies with relatively robust research designs with supplemental discussion from other studies where merited. Overall this body of work points to benefits of RRFBs. However, only one study employed a controlled before-and-after study design, which is considered the most effective approach for demonstrating causal effects of RRFBs. The findings of the controlled before-and-after study indicate that RRFBs did not have a significant impact on driver yielding and pedestrian looking behavior (Porter et al., 2016). However, the lack of effect observed in this study may have been due to a model misspecification, as noted above.

3.0 METHODS

OVERVIEW

In light of the gap in knowledge about the performance of RRFBs in small and rural communities, this observational analysis addresses two research questions. We first evaluate whether RRFBs are effective in the context of small cities and towns across Vermont. Second, we evaluate whether RRFBs are effective in small city and town centers as well as rural transition zones, where drivers are moving from high-speed rural areas to lower-speed towns with higher levels of pedestrian activity.

We use a controlled before and after study to evaluate these research questions at six locations with an RRFB (or similar pedestrian-activated LED embedded sign treatment) and at six similar paired control locations. We collect video recordings at each pair of locations simultaneously before and after the RRFB is installed. We then observe recorded pedestrian crossings and code key variables using robust content analysis techniques.

We evaluate RRFB effectiveness using compliance and safety-related outcomes. Our compliance measures include vehicle yielding and pedestrians crossing outside of crosswalks. Our safety-related measures include risky vehicle stopping position, sudden vehicle stops, and pedestrians stepping into the roadway before drivers yield. We evaluate the effect of RRFB installation on these outcomes while controlling for potentially confounding factors (such as pedestrian type, visibility, and time of day) that we identify based our review of prior literature. We then employ difference-in-difference analysis and multivariate modeling to evaluate our research questions.

STUDY DESIGN

We evaluate changes in driver and pedestrian behavior due to the installation of RRFBs using a before and after controlled design to demonstrate causal effects (Figure 1). The before and after observation allows us to evaluate effects that likely result from the RRFB installation, while the simultaneous observation of similar paired control locations allows us to separate the effects of other factors that vary over time, such as changes in weather, daylight hours, traffic levels, and share of drivers or walkers that are local. This study design allows us to better isolate the effect of the RRFB itself so that we have greater confidence that observed changes are causal.

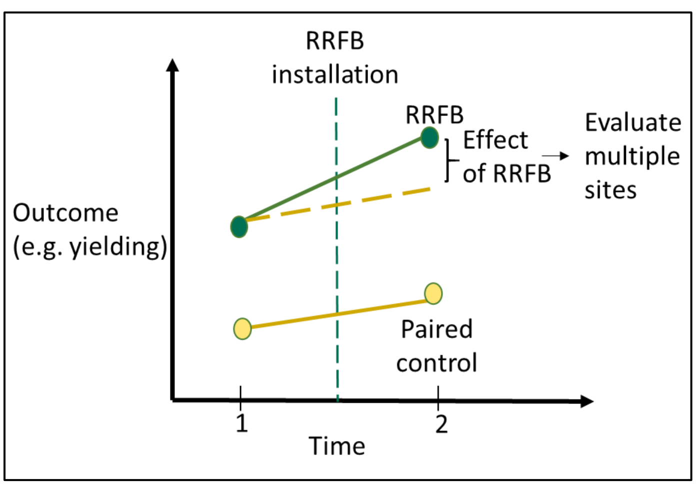

Figure 1: Paired controlled before and after study design

We identify and pair each RRFB installation site with a similar crossing location. Within each pair, one location serves as a treatment, with a traditional crosswalk in the "before" period and an RRFB installation in the "after" period. The paired location serves as the control site and does not change over the study period, with either an RRFB or a traditional crosswalk in both the "before" and "after" period. We observed all pairs simultaneously for 4 to 10 days before the RRFB installation, and again for 4 to 10 days following the RRFB installation. Our data includes approximately 120 total days of video recordings collected between April 2021 and August 2022.

STUDY LOCATIONS

We selected potential RRFB installation (treatment) locations based on inquiries with jurisdictions identified by the Vermont Agency of Transportation (VTrans) as planning an RRFB installation during the study period. Locations that provide a range of contexts (small cities and towns and rural transition zones) and fit the window of our study period were prioritized for inclusion in the study. Control locations were selected based on proximity to the treatment location as well as similarities in the context (town size and central vs. transition zone location), posted vehicle speeds, number of lanes, school zone, sidewalk configuration, estimated annual average daily traffic (AADT), and nearby land uses.

Figure 2 shows the location of the twelve study sites (six treatments paired with six controls). One pair is in the City of Burlington, which has a population of 44,890 and is the largest municipality in the largely rural state of Vermont. Two treatment locations are in the Town of Colchester with paired control locations in the Town of Milton, with 2020 populations of 17,524 and 10,706 respectively (US Census, 2020). One pair is in the Town of Middlebury, home to Middlebury College, with a 2020 population of 9150. The final two pairs are in the City of Montpelier, the state capital, which had a population of 8000 in 2020. The Montpelier treatment locations were included because they were identified as sites where RRFBs would be installed. However, the actual installations are pedestrian-activated flashing LEDs embedded in the border of a pedestrian crossing sign, which is similar to an RRFB, albeit with smaller round beacons located on the border of the sign instead of rectangular flashing beacons.

Table 2 shows each treatment and control pair and their pairing characteristics. Pairs were selected based on insights about important contextual factors that relate to compliance and safety in the review of prior literature. The number of lanes is omitted from the table since all treatments and controls have two lanes. Locations are characterized as being centrally located when they are well within towns and cities where land uses are relatively dense and travel speeds are relatively consistent. Transition zone is defined based on two factors: 1) their location between the center of town and more rural or outlying areas, and 2) whether the speed limit drops as a vehicle approaches the location from the inbound direction (see Table 2 and Appendix 2. In all but one case these factors are consistent and determining a transition zone is straightforward. The determination is more challenging at the Colchester "Main St. / Cobbleview Dr." treatment location, which we classify as a rural transition zone because of its location and the feel of the route, although the speed does not change approaching the crosswalk from outside of town. Additional information about each location is included in Appendix 1.

The study originally included five additional potential treatment locations and five pairs in Milton, St. Johnsbury, Burlington, Winooski, and Pittsford. However, these locations are excluded because the RRFB installation was not completed during the data collection period (Milton, Winooski), there are not enough pedestrians crossing in "before" video recordings (St. Johnsbury, Pittsford), or there is not a secure location to install a video camera (Burlington).

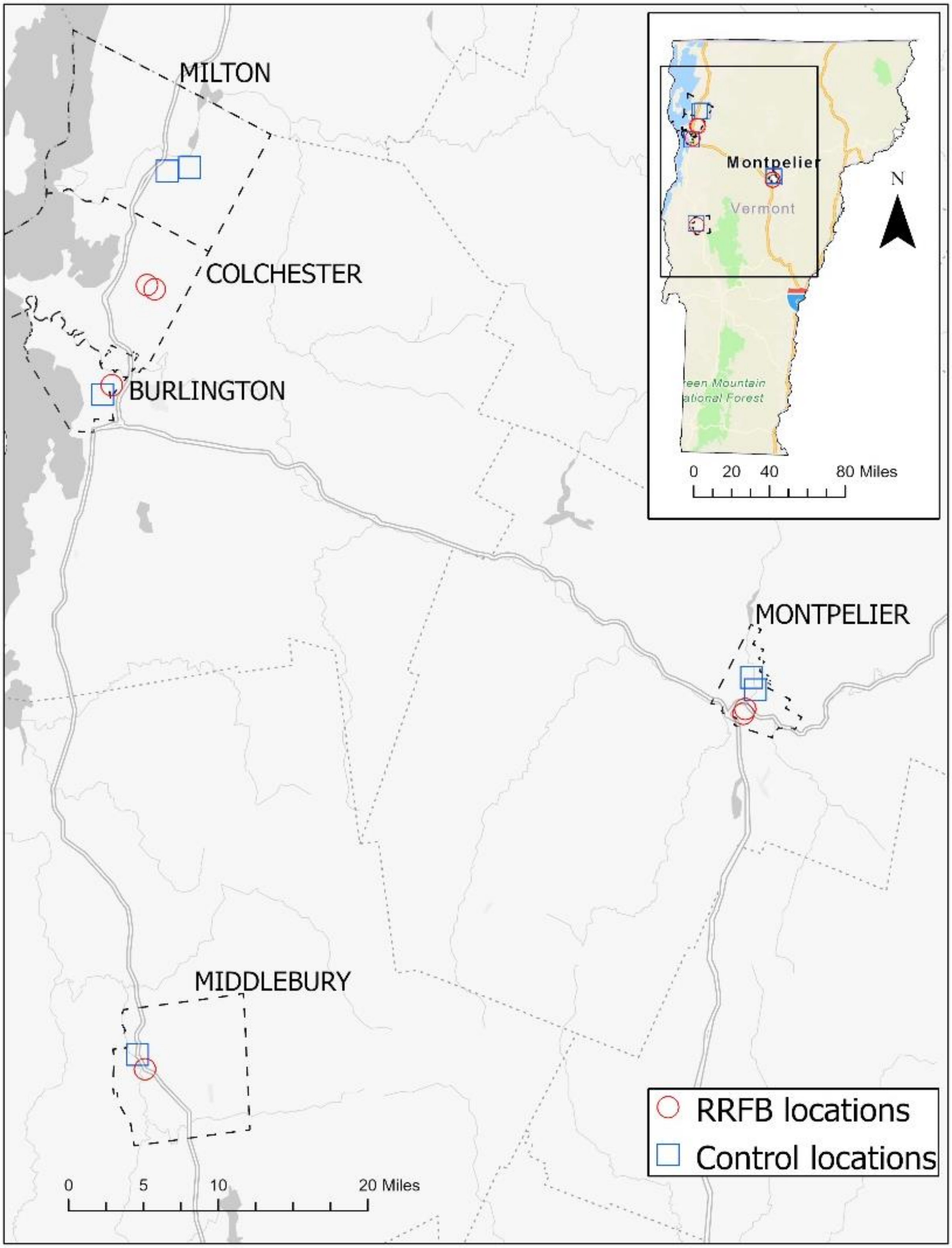

Figure 2: RRFB treatment and control sites

Table 2: Pairing characteristics of RRFB treatment and control locations

Pair Name	Location	Location type	Context	Pop density[1] (ppl/sq mi)	Speed limit (mph)	School zone	Notable nearby land use	AADT[2]	Crosswalk marking[3]
Burlington	East Ave / Bilodeau Ct.	Treatment	Central	9359	25	N	Homes, university hospital	6748	Fresh
	400 block S. Prospect St.	Control (crosswalk)	Central	3591	25	N	Homes, university campus	1652	Faded
Colchester (Pair one)	Main St. / Cobbleview Dr. (Colchester)	Treatment	Transition	226	35	N	Church, library, historical society	7977	Not visible
	US 7 / Chrisemily Ln. (Milton)	Control (RRFB)	Transition	538	35	N	Vet hospital, homes, daycare	11310	Not visible
Colchester (Pair two)	400 block Main St. (Colchester)	Treatment	Central	226	35	Y	Ice cream shop, park, school	7977	Faded
	River St. / Rebecca Lander Dr. (Milton)	Control (RRFB)	Central	1180	25	Y	Ice cream shop, school, dentist	8286	Not visible
Middlebury	US 7 Court St. / Creek Road	Treatment	Transition	470	25	N	Commercial mall	10270	Faded
	Main St. / Pleasant St.	Control (crosswalk)	Transition	635	25	N	Church, square	8461	Faded
Montpelier (Pair one)	VT 12 Northfield St. / Derby Dr.	Treatment	Transition	579	30	N	Church, motel, homes	4062	Faded
	597 Elm St. / N Park Dr.	Control (crosswalk)	Transition	504	30	N	Homes, park	4204	Faded
Montpelier (Pair two)	VT 12 Northfield St.	Treatment	Transition	579	25	N	Homes	4062	Faded
	VT 12 Elm St \ Pearl St.	Control (crosswalk)	Transition	504	25	N	Homes	5373	Fresh

[1] Estimated based on census block group data (US Census, 2020).

[2] 2020 Annual Average Daily Traffic (AADT) is estimated based on the VTrans 2021 AADT Report (VTrans, 2021).

[3] Crosswalk markings were assessed during the "before" data collection period.

MEASURED VARIABLES

We identify and measure dependent (outcome) and independent variables that influence them based on our research questions and insights from prior literature. These variables include attributes of crossing locations, vehicles, pedestrians, and their respective behaviors. We measure these variables during each vehicle-pedestrian *interaction*, which we define as situations where one or more pedestrians wait to cross and/or cross in the presence of one or more vehicles. Table 3 summarizes the dependent and independent variables used in this study, which we describe in detail below.

RRFB EFFECTIVENESS (OUTCOMES OR DEPENDENT VARIABLES)

We focus on driver and pedestrian behaviors that we characterize as 1) compliance-related outcomes (drivers' yielding behavior and pedestrians' crosswalk usage) and 2) safety-related outcomes (vehicle stopping behavior and pedestrians stepping into the roadway before drivers yield) (Figure 3). These measures are indications of RRFB effectiveness and serve as a surrogate for safety because data on collisions are too sparse to support meaningful conclusions.

COMPLIANCE-RELATED OUTCOMES

VEHICLE YIELDING

We evaluate whether a vehicle yields when a pedestrian attempts to cross the roadway while a vehicle is within an appropriate stopping distance. We exclude vehicles that are within the stopping distance when the pedestrian arrives, those that turn just before or after the crosswalk, and those that stop because the vehicle in front of them has stopped. As a result, there is a maximum of one yielding car per lane for each pedestrian crossing event. We estimate stopping distances for each location based on the posted speed limit (see Appendix 7). We calculate the stopping distance SD:

$$\boldsymbol{SD = D_r + D_b}$$

where D_r is the reaction distance:

$$\boldsymbol{D_r = v_0 t_r}$$

and D_b is the braking distance:

$$\boldsymbol{D_b = \frac{{v_0}^2}{2a}}$$

The parameters in these equations are defined as follows:

$\boldsymbol{v_0}$ = initial vehicle velocity (in miles per hour), assumed to be the posted speed limit,
t_r = reaction time (in seconds), assumed to be two seconds, and
$\boldsymbol{a}$ = the rate of deceleration (in feet per second^2), assumed to be 10 ft/s^2.

We create three measures that represent yielding-related outcomes. The first measure, *driver-level yielding*, is a binary variable that reflects a vehicle's decision to stop for a pedestrian (or not). The second variable is a *pedestrian-level yield rate*, which represents the share of vehicles that yielded for a pedestrian, where the denominator is only those vehicles that are included using the criteria noted above. This variable is continuous and varies from 0 to 100%. The third variable is the *pedestrian wait time*, which is a function of how soon drivers yield, traffic levels, and pedestrian behavior, and is estimated as the difference between the pedestrian arrival time and pedestrian crossing time. Previous studies have shown that crossing violations are more likely as pedestrian waiting time increases (Brosseau et al., 2013).

Table 3: Summary of variables

Variables	Description	Variable type	Units
Dependent			
Pedestrian wait time	Time between when pedestrians arrive until they start crossing	Continuous	seconds
Pedestrian-level yield rate	Share of vehicles that yield to a pedestrian	Continuous	% of vehicles that yield
Driver-level yielding	Driver yields to pedestrian	Binary	1 = yes
Pedestrian crossing out of crosswalk	Pedestrian crosses outside the crosswalk	Binary	1 = yes
Vehicle stops suddenly	Driver stops suddenly or reacts quickly	Binary	1 = yes
Pedestrian in roadway before drivers yield	Pedestrians start crossing before drivers yield	Binary	1 = yes
Risky vehicle stopping position	Vehicle stops close to the crosswalk	Binary	1 = yes
Independent			
Poor visibility	Visibility based on time of day and weather (rain or fog)	Binary	1 = yes
Sun in eyes	Sunny conditions and the sun is angled toward the driver's line of sight	Binary	1 = yes
Runner	Pedestrian is a runner	Binary	1 = yes
Biker	Pedestrian is a biker	Binary	1 = yes
Grouped crossing	Two or more people crossing	Binary	1 = yes
Presence of vulnerable users	Pedestrian(s) crossing appear to include kids under 10, elderly adults, and people with disabilities or walking with assistance	Binary	1 = yes
Presence of pets	Pedestrian has a pet	Binary	1 = yes
Nearside	Vehicle lane of travel relative to pedestrian	Binary	1 = yes
Central zone	Crossing location relative to town or city center	Binary	1 = yes (central)
			0 = transition
RRFB activation	Whether the RRFB is present and activated during the crossing	Categorical	Ref: no RRFB
			RRFB not activated
			RRFB activated
Peak hour	Time of day	Categorical	Ref: Not peak
			Morning peak
			Evening peak
Weekend	Crossing is on a weekend day	Binary	1 = yes
"After" study phase	Before or after phase of the study	Binary	1 = yes
Location pairs	In what pair are the locations	Categorical	ref: Burlington pair
			Colchester pair 1
			Colchester pair 2
			Middlebury pair
			Montpelier pair 1
			Montpelier pair 2

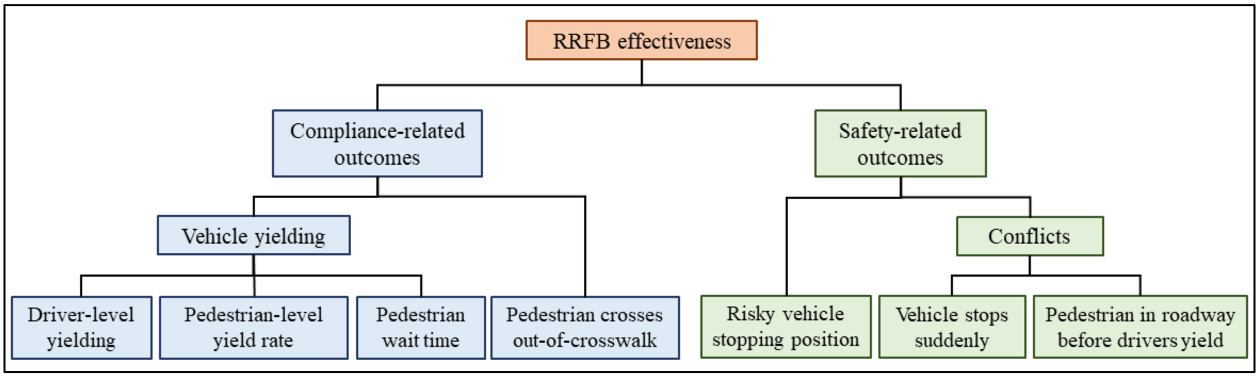

Figure 3: RRFB effectiveness outcomes (dependent variables)

PEDESTRIAN CROSSES OUT-OF-CROSSWALK

We measure pedestrian crosses out-of-crosswalk as a binary variable. We code a pedestrian as out of the crosswalk if they cross the roadway outside of a buffer zone that includes the crosswalk and the area around the it (see Figure 4 for an example). The buffer zone's boundary extends to a distance equal to the width of the crosswalk on each side.

SAFETY-RELATED OUTCOMES

RISKY VEHICLE STOPPING POSITION

A vehicle's stopping position can provide insight about drivers' attention to pedestrians' presence and maintenance of a safe space around pedestrians. We measure a risky stopping position based on how close cars stop relative to the crosswalk (Figure 4). One important factor in a vehicle's stopping position is that it depends on the time it takes for the driver to identify the pedestrian and react. An RRFB may increase drivers' awareness of a pedestrian, resulting in fewer instances of vehicles stopping close to the crosswalk. On the other hand, RRFBs may also lead to increased pedestrian assertiveness, which may cause a car to stop closer to the crosswalk. We measure *risky vehicle stopping position* as a binary variable, where stopping close to the crosswalk and rolling represents a risky stop and stopping far are not considered a risky stop.

CONFLICTS

We evaluate two types of driver-pedestrian conflicts. First, we measure whether a vehicle stops suddenly as a binary variable reflecting whether the car came to a sudden stop. The second variable measures whether a pedestrian is in the roadway before drivers yield. It is also coded as a binary variable indicating whether the pedestrian stepped into the roadway while one or more oncoming vehicles were moving.

FACTORS THAT INFLUENCE RRFB EFFECTIVENESS (INDEPENDENT VARIABLES)

We identify variables that may influence RRFB effectiveness based on prior literature. The first set of variables that we consider are static at each location during this study period, such as the number of lanes for each location, surrounding population density and land use, typical traffic levels, and crosswalk marking type. As noted above, these types of characteristics are used to identify control pairs so they are not modeled explicitly in the analysis. The exception is for static variables that represent whether the crossing is located in the center of town or in a rural transition zone (split into inbound and outbound depending on vehicle direction), which is explicitly modeled because it is the focus of our research question.

Figure 4. Example of video footage for different crossing scenarios

Other factors that are dynamic also affect RRFB effectiveness. These variables change throughout the study or observation periods. They include vehicle characteristics such as whether the sun is in the driver's eyes and whether the vehicle is traveling on the side of the road where the pedestrian is approaching the crosswalk versus on the other side of the road (nearside versus farside). Pedestrian characteristics include whether the pedestrian is a runner, biker, has a pet, is vulnerable, and whether they are crossing in a group. In the context of traffic safety, vulnerable road users often refer to road users who are most at risk of injury or death in the event of a crash, including pedestrians, bicyclists, children, people with disabilities, and any other non-motorized road users. For our study, we classify elderly, those who require walking assistance, and children as vulnerable users. Although the term "vulnerable" can also refer to characteristics such as race, ethnicity, and income, these characteristics were not included in this analysis in part because it would not be possible to observe them using our data collection methods.

Finally, we include variables that capture the context, including visibility (which is a function of weather), peak hour, weekend or weekday, and our study focus: presence of an RRFB, which changes for some locations in the before versus after data collection period. When an RRFB is present, we also measure whether it is activated.

DATA COLLECTION

In order to collect data for each of the modeled variables, we recorded video at each site for 4 to 10 days simultaneously for each pair of study locations. Simultaneous data collection at paired sites ensures that we control for most temporal factors such as weather, day of the week, and season. Video recordings also allow the team to view pedestrian crossings multiple times to improve quality control.

At each site, we secured a SPACK CountCam 2 video camera to a utility pole at a height of 10 to 20 feet, with the camera aimed toward the crosswalk. Cameras were placed at a distance that was close enough to capture crossing pedestrians, vehicles, and RRFBs, but far enough to capture the minimum distance required for the cars to stop (when feasible). Figure 5 shows an example of camera positioning and footage. The same camera position was used at each location during each of the observation periods[2].

Cameras were placed during periods that included at least two weekend days and at least some fair weather. They were also placed during periods that avoided construction activities near crossing locations and holidays and unusual events that might dramatically change traffic patterns. "Before" data were collected in 4 to 10 day periods from April through June 2021. RRFB installations occurred between June and December 2021. "After" data were collected from April through August 2022, providing 6 to 12 months between RRFB installation and "after" data collection at each site. The camera did not have night vision, so only recordings collected during daylight hours were included in this analysis.

Table 4 shows the timeline of observations and RRFB installation as well as the number of crossings observed at each location when cars are around (interactions).

DATA SAMPLING AND CODING

We used a rigorous data sampling and coding process to ensure a robust data collection process. To process the data, we first viewed each recording between dawn and dusk (when pedestrians were visible) to identify pedestrian crossings that include pedestrian/vehicle interactions, which were defined as those where the pedestrian waited to cross and/or crossed in the presence of one or more vehicles. After identifying all crossings with interactions, we selected 30 interactions at each location during each time period (before or after) using stratified random sampling.

These 30 interactions were then coded in an iterative procedure designed to ensure consistent and reliable coding of variables (Figure 6). In summer 2021 we began by creating a draft coding guideline that described how each variable would be coded. Two researchers then used this guideline to separately code an identical sample of the data (20 to 40 interactions) using just the guideline (without conferring), compared codes, and then discussed differences in codes in consultation with a third researcher. The guideline was then revised to capture the clarifications that were discussed. This process was repeated (using a new stratified random sample of data each time) until coding of identical samples was relatively consistent when the two coders compared.

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[2] One exception to this is Montpelier (Pair one) VT 12 Northfield / Derby Dr. We changed the location of the camera due to heavy vegetation blocking the camera view. The previous stopping distances are captured in the new recordings so data remain consistent.

(a) Camera installation (b) Camera setup (c) Camera view

Figure 5: CountCam installation and use at the RRFB treatment location in Middlebury.

Table 4. Timing of observations and RRFB installation

Pair Name	Location	Before phase (2021)	RRFB installed	After phase (2022)	Days recorded	Interactions observed
Burlington	East Ave / Bilodeau Ct.	Apr 14 - 20	June 2021	Apr 6 - 12	12	845
	400 block S. Prospect St.					200
Colchester (Pair one)	Main St. / Cobbleview Dr. (Colchester)	May 12 - 16, June 11 - 17	Dec 2021	Apr 22 - 26, June 2 - 6	24	82
	US 7 / Chrisemily Ln. (Milton)					94
Colchester (Pair two)	400 block Main St. (Colchester)	May 12 - 16	Dec 2021	Apr 22 - 26, June 2 - 6	14	216
	River St. / Rebecca Lander Dr. (Milton)					157
Middlebury	US7 Court St. / Creek Road	Apr 7 - 11	July 2021	Aug 4 - 9	10	158
	Main St. / Pleasant St.					253
Montpelier (Pair one)	VT 12 Northfield / Derby Dr.	Apr 30 - May 4	July 2021	June 16 - 20	8	104
	597 Elm St. / N Park Dr.					77
Montpelier (Pair two)	VT 12 Northfield	Apr 30 - May 4	July 2021	June 1 - 20	8	98
	VT 12 Elm St \ Pearl St.					196

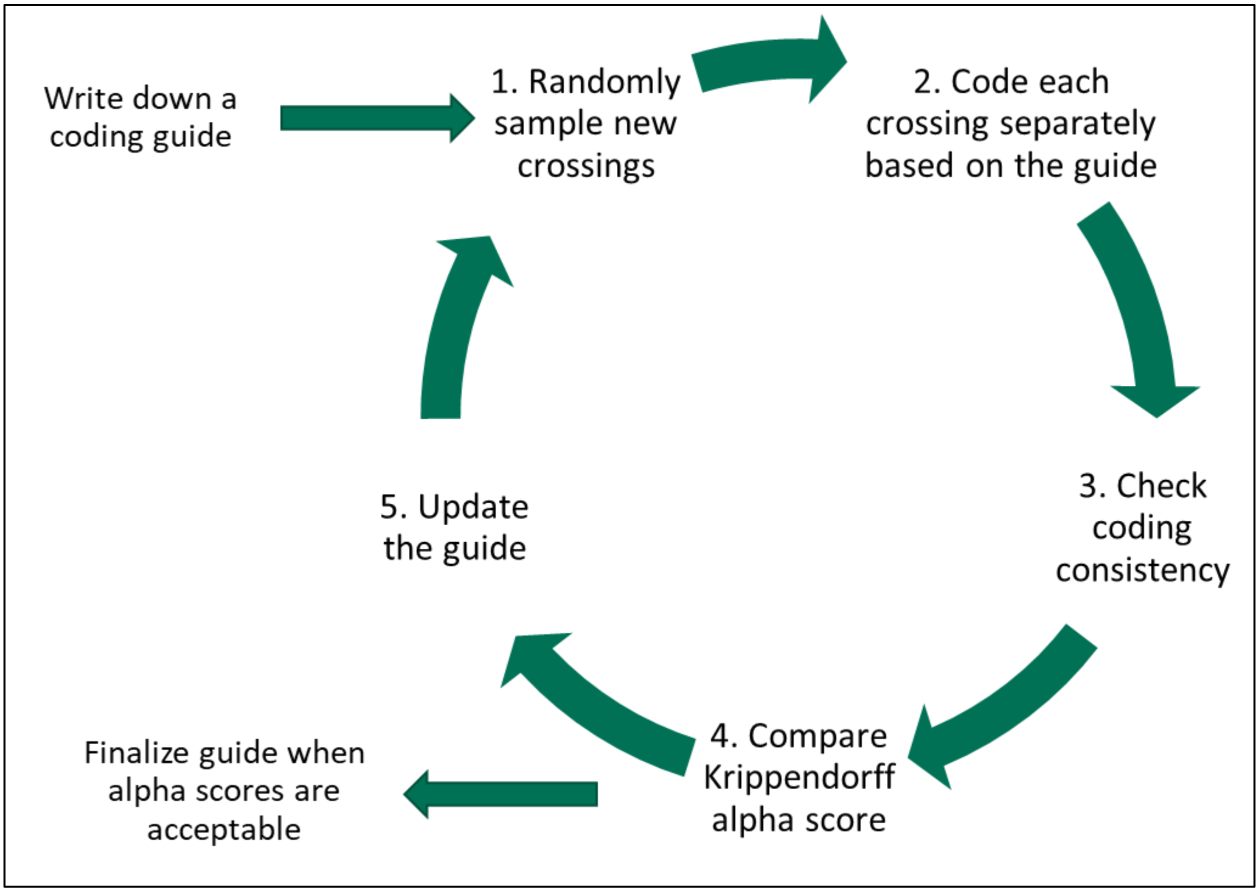

Figure 6: Procedure for developing the video coding guide

Once the codes converged, both coders coded a larger sample of about 100 interactions. The coders quantitatively evaluated the consistency of their codes using Krippendorff's alpha, a widely-used measure of intercoder reliability that allows analysts to determine whether codes are consistent and reliable, where a value of 1 indicates full agreement and 0 indicates no agreement. Krippendorff's alpha is a more accurate measure than percent agreement because it accounts for both the rate of agreement as well as the odds that agreement will occur given the underlying distribution of a variable. It can be used regardless of the number of coders, sample size, missing data, or type of data (Hayes & Krippendorff, 2007). Coded data with a value of 0.8 or higher is generally regarded as robust. Once Krippendorff's alpha values were estimated for all variables, scores were evaluated and variables with scores of less than 0.8 were scrutinized for differences. Different coding approaches were then resolved through discussion of all three researchers, further revising the coding guideline. This process was repeated (using a new stratified random sample of data each time) until all codes needed for modeling scored 0.8 or greater. Variables that were less critical and had a score of less than 0.8 were omitted from the analysis.

We created the final guideline using this procedure during the summer of 2021, relying on "before" data (which included interactions at both traditional crosswalks and RRFBs because one of the control locations includes an RRFB.) Once the guideline was finalized, we coded the full "before" dataset using the final guide. We rechecked intercoder reliability throughout the summer (using data from early and late for both coders).

One benefit of this process was the creation of an explicit and thorough guide describing what each variable represents. The coding guide formalized the coding method to reduce the risk that two different researchers code the data differently. It also prevents substantial coder "drift" over time. This drift is particularly important in this study since it spanned two summers and the coders could drift from the consensus coding frame developed in the before period. The use of intercoder reliability also allowed us to monitor the consistency of coding as the project progressed.

After collecting the second round of data for "after" measurements in 2022, we used the same process as 2021 to identify interactions in each video recording. Only one coder coded the "after" video recordings. Before coding the "after" recordings, the coder reviewed the coding guide and several samples of "before" data that he had not previously coded to refresh his familiarity with the guide and ensure he could code consistently with the 2021 coding. Unlike the 2021 process, the 2022 comparative coding process only involved the coder reflecting and reviewing, and did not include any changes to the guideline. Once the 2022 coder was fully "refreshed" he coded a sample of 103 interactions that had been coded by the second coder in 2021. He then assessed Krippendorff's alpha to ensure consistency with 2021 codes. Variables with a score that fell below the 0.8 threshold in the two 2021 rounds of reliability analysis or the final 2022 round were omitted from this analysis with the exception of the variable for "sun in the eyes", which was 0.78.

Table 5 summarizes the interactions coded at each location in each study period. We coded between 28 and 30 interactions at most locations in each time period, with fewer (22 to 25) at one of the Colchester pairs that had lower pedestrian volumes. Table 6 summarizes key characteristics of all dependent and independent variables observed. The final coding guide and estimated Krippendorff's alpha estimates are included in Appendix 3.

ANALYSIS

We evaluate the effectiveness of RRFBs in Vermont using both a difference-in-difference (DID) and multivariate regression analyses.

DIFFERENCE-IN DIFFERENCE-FRAMEWORK

A difference-in-difference (DID) analysis approach estimates the causal effect of RRFB installations using a relatively simple comparison of the difference in the change in outcomes at each RRFB treatment location relative to its paired control location where no change in the crossing occurred. The results of the difference-in-difference analysis are robust for cases where time-varying changes are relatively consistent at both the RRFB and the control location, so that confounding factors (such as weather or pedestrian characteristics) do not bias the results. We use the difference-in-difference (DID) analysis to evaluate our first research objective, which is to determine whether RRFBs are effective in the context of Vermont's small cities and towns.

As illustrated in Figure 1, we can graphically represent the difference-in-difference estimate by graphing the outcomes for each location before and after the treatment. Using the path of change for the control location (solid yellow line), we calculate a counterfactual path for the treatment location (gray dotted line). The counterfactual path represents the change that we would expect to occur at the treatment location if the treatment has no effect, so it behaves similarly to the control location. The difference between the counterfactual point and actual observed data after the treatment occurs is our estimate of the change caused by the treatment.

Table 5: Data collection summary

Pair Name	Location and type	Study phase	Number of pedestrian/ vehicle interactions	Weekend	Good visibility	Sun in drivers' eyes
Burlington	East Ave / Bilodeau Ct. Treatment	Before	29	24%	69%	10%
		After	30	23%	50%	17%
	400 block S. Prospect St. Control (traditional crosswalk)	Before	30	27%	60%	30%
		After	30	20%	77%	20%
Colchester (Pair one)	Main St. / Cobbleview Dr. Treatment	Before	30	57%	100%	57%
		After	25	44%	100%	16%
	US 7 / Chrisemily Ln. Milton Control (RRFB)	Before	25	24%	100%	24%
		After	22	46%	100%	18%
Colchester (Pair two)	400 block Main St. Colchester Treatment	Before	30	57%	97%	7%
		After	29	45%	93%	17%
	River St. / Rebecca Lander Dr. Milton Control (RRFB)	Before	28	14%	100%	21%
		After	30	33%	100%	7%
Middlebury	US 7 Court St. / Creek Road Treatment	Before	29	17%	100%	90%
		After	28	25%	96%	25%
	Main St. / Pleasant St. Control (traditional crosswalk)	Before	29	24%	100%	86%
		After	30	17%	87%	0%
Montpelier (Pair one)	VT 12 Northfield / Derby Dr. Treatment	Before	30	43%	80%	17%
		After	30	43%	100%	3%
	597 Elm St. / N Park Dr. Control (traditional crosswalk)	Before	30	53%	80%	10%
		After	30	23%	100%	30%
Montpelier (Pair two)	VT 12 Northfield Treatment	Before	28	54%	86%	7%
		After	29	24%	100%	10%
	VT 12 Elm St. / Pearl St. Control (RRFB)	Before	28	64%	79%	7%
		After	30	27%	100%	3%
Total	-	-	689	35%	90%	22%

Table 6. Descriptive statistics of dependent and independent variables

Dependent			
Continuous variables	**Units**	**mean**	**SD**
Pedestrian waiting time	seconds	7.967	6.86
Pedestrian-level yielding rate	% of vehicles yielding	57.179	42.7
Binary variables	**Units**	**n**	**share**
Driver-level yielding	1 = yes	632	41.5%
Pedestrian crossing out of crosswalk	1 = yes	46	6.7%
Vehicle stops suddenly	1 = yes	81	11.8%
Pedestrian in roadway before drivers yield	1 = yes	189	27.4%
Risky vehicle stopping position	1 = yes	452	71.5%
Independent			
Binary	**Units**	**n**	**share**
Poor visibility	1 = yes	73	10.6%
Sun in eyes	1 = yes	153	22.2%
Runner	1 = yes	38	5.4%
Biker	1 = yes	73	10.6%
Grouped crossing	1 = yes	194	28.2%
Presence of vulnerable users	1 = yes	52	8.3%
Presence of pets[1]	1 = yes	92	13.4%
Nearside	1 = yes	373	54.1%
Central zone (vs. transition)	1 = yes (central)	453	65.7%
RRFB activation	Ref: no RRFB	354	51.4%
	RRFB not activated	148	21.5%
	RRFB activated	187	27.1%
Peak hour	Ref: Not peak	397	57.6%
	Morning peak	110	16%
	Evening peak	182	26.4%
Weekend	1 = yes	237	34.4%
"After" study phase	1 = yes	343	49.8%
Location pairs	ref: Burlington pair	119	17.3%
	Colchester pair 1	102	14.8%
	Colchester pair 2	117	17%
	Middlebury pair	116	16.8%
	Montpelier pair 1	115	16.7%
	Montpelier pair 2	120	17.4%

MULTIVARIATE MODELING

We also use multivariate regression analysis to address our research questions. This allows us to evaluate differences in outcomes while providing explanatory contributions from independent variables. It is also more robust than the difference-in-difference approach because it controls for other observed time-varying factors that may differ between the treatment and control location across the study periods. We use binomial logistic regression to evaluate the binary outcome variables (including driver-level yielding, vehicles stopping suddenly, pedestrians crossing out of the crosswalk, pedestrians in the roadway before drivers yield, and risky vehicle stopping position). To evaluate continuous outcomes (pedestrian-level yielding rate and pedestrian wait time), we use ordinary least squares (OLS) linear regression models.

For each outcome modeled, we formulate two models. The first set of models captures variation in outcomes that are specific to each pair of locations to understand variation across locations. The second set of models captures variation in outcomes in central versus rural transition zones. In both sets of models, we can isolate the effects of the RRFB on the outcome to address our first research question about the effectiveness of RRFBs in Vermont communities. The second set of models also provides insight into our second research question about the effectiveness of RRFBs across central and rural transition zones.

MODEL 1: VARIATION IN OUTCOMES AT EACH PAIRED LOCATION

In the first set of models, we evaluate the relationship between each outcome and most of the independent variables shown in Table 6. We include variables such as pedestrian and vehicle characteristics, conditions, and study phase both to control for them and estimate the magnitude of their effects on the outcome. We include a variable for RRFB activation to isolate the effect of the RRFB on the outcome to address our first research question. We also include a variable for each *location pair*, which provides an estimate of the fixed effects of each location pair. These location pair variables indicate the magnitude of the differences in outcomes across locations. Because this model controls for the location of the pairs, it cannot also include whether the location is centrally located or a transition zone because doing so would introduce multicollinearity into the models.

MODEL 2: VARIATION IN OUTCOMES FOR CENTRAL VERSUS RURAL TRANSITION ZONES

This set of models is similar to the first set. The outcome variables and the modeled independent variables are the same as in the first set of models, except that instead of including independent variables for each location pair, we include a *zone* variable. The zone variable specifies whether the location is a central location or a rural transition (and in some cases whether travel is inbound or outbound). The second set of models excludes pair variables to avoid multicollinearity. The inclusion of the RRFB activation variable again addresses our first research question. The inclusion of the zone variable allows us to evaluate differences in outcomes across zones to provide insight into our second research question.

4.0 RESULTS AND DISCUSSION

DIFFERENCE-IN-DIFFERENCE ANALYSIS

We summarize the difference-in-difference analysis graphically. Each graph shows the outcome (or average outcome) for each location in the "before" and "after" period. The counterfactual path, which represents our estimated outcome at the treatment location if no RRFB were installed, is also shown. Finally, vertical arrows summarize the absolute change of the outcome shown, illustrating RRFBs effects on outcomes as improving (green) or worsening (orange). Results that change by less than 5% do not have arrows and are treated as no change. For waiting time, we treat less than 0.8 second as no change.

COMPLIANCE-RELATED OUTCOMES

Figure 7 shows the difference-in-difference results for driver and pedestrian compliance-related outcomes at the four RRFB installation locations and two similar LED embedded locations in Montpelier, Outcomes shown include vehicle yielding measures and pedestrians' out-of-crosswalk crossings.

Recall that both yielding measures reflect driver behavior, with the pedestrian-level yield rate representing pedestrians' experiences of driver yielding behavior (the share of cars that yield to each pedestrian). Looking at Figure 7, we can see the average pedestrian-level and driver-level yield rate across all observed vehicle-pedestrian interactions at each location and in each time period. The counterfactual path is shown as a dotted line, with the absolute change in the pedestrian-level yield rate shown as a red or green up or down arrow. In this case, looking at all six locations the percent difference ranges from -37% to 43%. This indicates that the installation of RRFBs or similar treatments results in a change in driver compliance by between -37 % to 43% relative to what we would expect if an RRFB or similar treatment had not been installed. Looking at just the RRFB locations, we observe improvements of 12% to 43%. As discussed later in this report, the decrease in yielding rate for both Montpelier locations may be attributable to differences in the LED lights used at these locations, which are not RRFBs.

Figure 7 also shows the average pedestrian wait time difference-in-difference results. Two RRFB locations show an improvement (which is a decrease) of between 0.8 to 2.6 seconds, three locations show almost no change, and one of the Montpelier locations worsens with an increase in wait time of 6 seconds. The increase in waiting in Montpelier may relate to the installation of non-RRFB treatment, which is also related to a small reduction in driver compliance. Based on video observations and comparisons with "before" data, we posit that it may also be attributable to a reduction in out-of-crosswalk crossings, which may have caused pedestrians to wait longer instead of using the gap between cars to step into the road.

The rate of pedestrians' out-of-crosswalk crossing greatly improves with RRFBs and similar treatments, with improvements (which are reductions) ranging from 10% to 14% for four out of six crossings and no change for one location (Figure 7). This promising result indicates that pedestrian compliance improves with the installation of RRFBs and similar treatments, which is likely to improve safety. We exclude the Burlington pair from this part of the difference-in-difference analysis because no out-of-crosswalk crossings were observed at the treatment location, likely because it has a limited access path at one end.

Overall, the difference-in-difference analysis points to improvements in out-of-crosswalk crossings for RRFBs and similar treatments. RRFBs are related to improvements in yielding behavior and pedestrian wait time. The mixed results for waiting time and yielding behavior may be at least in part due to differences in the LEDs used in the RRFBs in Montpelier, which makes these installations non-RRFBs.

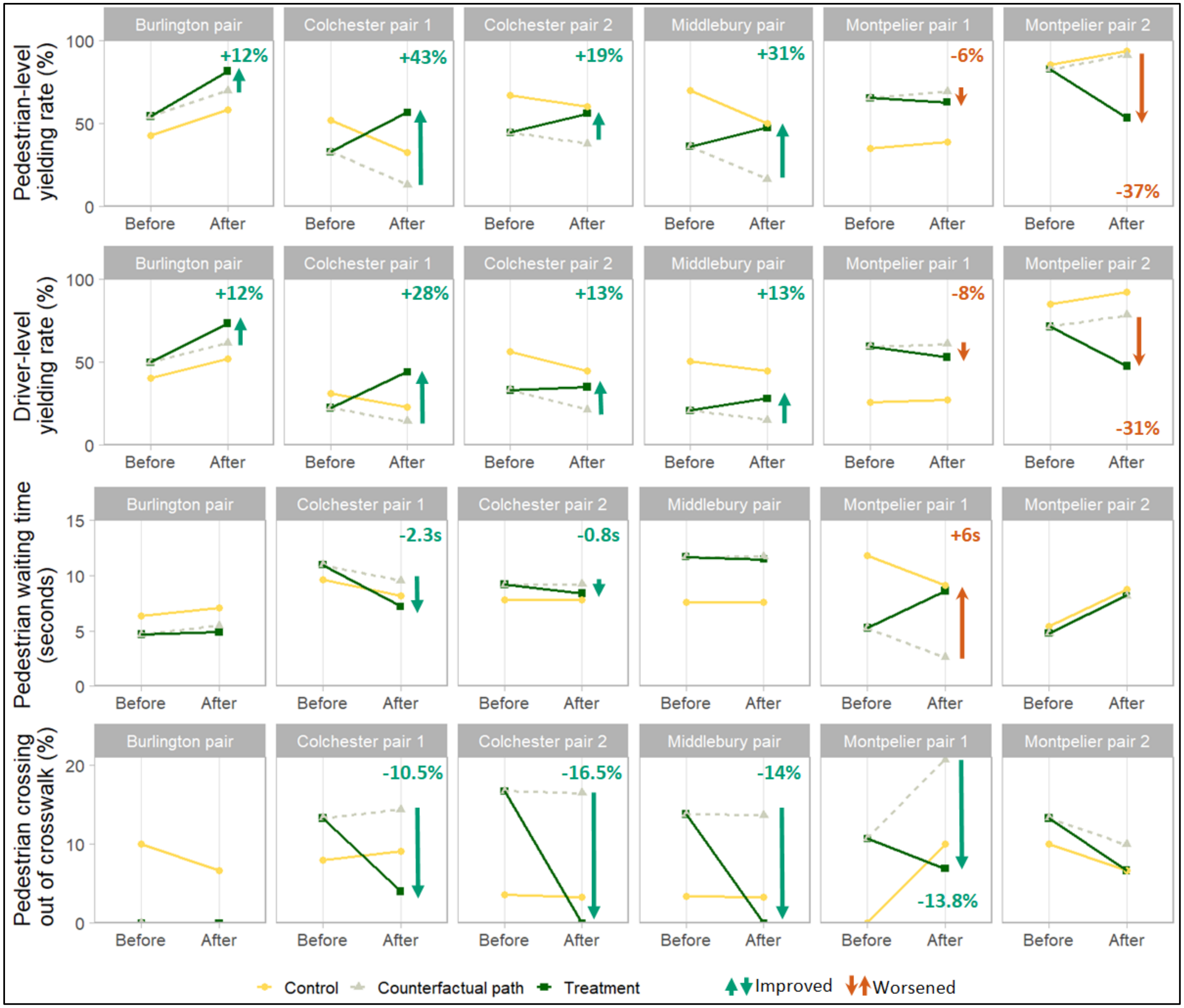

Figure 7. Difference-in-difference results for driver and pedestrian compliance-related outcomes

Safety-Related Outcomes

Figure 8 shows the difference-in-difference results for safety-related outcomes including risky vehicle stop positions, vehicles stopping suddenly, and pedestrians entering the roadway before drivers yield.

The rates of risky vehicle stop position improves (decreases) for three RRFB (and similar treatment) installations, while two others worsen (increase), and one has no change (Figure 8). Improvements at the three locations may be due to beacon activation or an increase in pedestrians' assertiveness (pedestrians waiting closer to the curb while waiting to cross.) Pedestrian assertiveness difference-in-difference results are not shown in the main body of this report but are included in Appendix 4.

The rate at which vehicles stop suddenly improves (reduces) in three of six treatment locations, with an increase (worsening) at one location and no change at two locations (Figure 8). At the same time, pedestrians' rate of crossing before cars yield improves at three locations and worsens at two locations.

Summary

The difference-in-difference (DID) analysis suggests that installing RRFBs in small and rural communities may improve compliance and safety. The analysis consistently shows that RRFBs and similar installations improve pedestrian out-of-crosswalk crossings. Evidence also suggests that RRFBs result in improvements in driver yielding, pedestrian wait times, and vehicles stopping suddenly. Evidence for vehicles stopping suddenly and pedestrians entering the roadway before drivers yield is inconclusive. Viewing difference-in-difference results alongside location attributes suggests that Montpelier installations (which are not RRFBs) may be less effective than other locations, with no clear trend across central and transition zone types (Table 7).

Figure 8: Difference-in-difference results for safety-related outcomes

Table 7. Summary of difference-in-difference (DID) Analysis

	Outcome	Burlington pair	Colchester pair 1	Colchester pair 2	Middlebury pair	Montpelier pair 1	Montpelier pair 2	Overall
Context	AADT	6748	7977	11310	8286	4062	4062	
	Speed	25	35	35	25	30	25	
	Zone	Central	Transition	Central	Transition	Transition	Transition	
	RRFB	Yes	Yes	Yes	Yes	No	No	
Compliance outcomes[1]	Pedestrian-level yielding rate	**Improved** (+12%)	**Substantially improved** (+43%)	**Substantially improved** (+19%)	**Substantially improved** (+31%)	**Worsened** (-6%)	**Substantially Worsened** (-37%)	**Improve (RRFB only)**
	Driver-level yielding	**Improved** (+12%)	**Substantially improved** (+28%)	**Improved** (+13%)	**Improved** (+13%)	**Worsened** (8%)	**Substantially Worsened** (31%)	**Improve (RRFB only)**
	Pedestrian wait time	**Small or no change** (-0.5s)	**Substantially improved** (-2.3s)	**Improved** (-0.8s)	**Small or no change** (<0.3s)	**Substantially Worsened** (6s)	**Small or no change** (0s)	**May improve (RRFB only)**
	Pedestrians crossing out-of-crosswalk	No Data	**Improved** (-11%)	**Substantially improved** (-17%)	**Improved** (-14%)	**Improved** (-14%)	**Small or no change** (-3%)	**Improve**
Safety-related outcomes[1]	Risky vehicle stop position	**Worsened** (+5%)	**Substantially improved** (25%)	**Small or no change** (-3%)	**Improved** (-14%)	**Substantially improved** (-39%)	**Worsened** (+11 %)	**Unclear**
	Vehicles stops suddenly	**Small or no change** (-3%)	**Improved** (-9%)	**Small or no change** (-2%)	**Substantially improved** (-9%)	**Improved** (-10%)	**Worsened** (+7 %)	**May improve (RRFB only)**
	Pedestrian in roadway before drivers yield	**Substantially improved** (-45%)	**Worsened** (+8%)	**Small or no change** (-3%)	**Substantially improved** (-25%)	**Substantially Worsened** (+18%)	**Improved** (-13.5%)	**Unclear**

[1] Color coding and summary text is as follows: 0% to <5% small or no change, 5% to 15% change, >15% substantial change.

MULTIVARIATE ANALYSIS

Next, we turn to our multivariate models, which we use to provide more robust estimates of the effects of RRFBs on compliance and safety. The multivariate models control for time-vary factors that may differ across pairs. We use two models that are interpreted slightly differently. We model binary outcome variables (such as whether a driver yields) using binomial logistic regression, which provides an estimated odds ratio. If the odds ratio is statistically significant, it represents the odds that an outcome will occur if the dependent variable occurs. A dependent variable increases the likelihood of the outcome occurring when it exceeds 1 and decreases the likelihood that the outcome will occur when it is less than 1. When modeling continuous outcome variables (such as how long a pedestrian waits), we use OLS regression models, which return a coefficient estimate. The coefficient represents the unit change in the outcome that corresponds to a unit change in the independent variable. When the coefficient for an independent variable is significant and greater than 0, it indicates that an increase in the independent variables is related to an increase in the outcome, whereas when the coefficient is significant and less than 0, it indicates that the independent variable is inversely related to the outcome.

All models include both before and after data. The tables that present model results indicate statistical significance with **bold font** and asterisks (*, **, and ***). Font colors indicate the direction of significant relationships, where blue indicates that an increase in a variable improves the outcome whereas red indicates that an increase in a variable worsens the outcome.

We include all six locations as "RRFBs" in the models shown below, although the two Montpelier locations are similar to RRFBs but are not RRFBs. We also run each model excluding the two Montpelier locations, with no effect on the model interpretation discussed below (alternative model results not shown).

MODEL 1: VARIATION IN OUTCOMES AT EACH PAIRED LOCATION

We first evaluate the relationship between our independent variables and the four compliance outcomes Table 8. This set of models controls for the fixed effects of each pair location. The table shows odds ratios for binary outcome variables (driver-level yielding and pedestrians crossing out-of-crosswalk) and OLS regression coefficients for continuous variables (pedestrian-level yield rates and pedestrian wait time). Significant results are indicated with bold font and asterisks as noted above. Note that some variables improve when they increase (pedestrian and driver-yielding), while others worsen when they increase (pedestrians crossing out-of-crosswalk, pedestrian wait time).

To evaluate the effect of activating an RRFB, we focus on the "RRFB Activation: Activated" row. This shows that drivers are 2.59 times more likely to yield when pedestrians activate an RRFB (an improvement), pedestrians experience a 22.75 times higher share of cars who yield when they activate the RRFB (an improvement), pedestrian wait times are not significantly different when the RRFB is activated, and pedestrians are 0.04 times as likely to cross out-of-crosswalk when they activate the RRFB (an improvement). The presence of an RRFB that is not activated does not significantly affect compliance. Overall, RRFBs show significant improvement for three of four compliance outcomes.

We can also evaluate the effects of our control variables on compliance outcomes. Timing relates to outcomes, with both morning and evening peak periods associated with improvements in driver yielding while the morning peak is also associated with shorter pedestrian wait times. These results may be a function of slower vehicle traffic or higher levels of pedestrian traffic during peak hours. In terms of pedestrian characteristics, our results indicate that groups of pedestrians see improved outcomes in terms

Table 8: Multivariate models of compliance outcomes (Model 1: Location effects)

Variables	Driver-level yielding[1]		Pedestrian-level yielding rate (%)[2]		Pedestrian wait time (secs)[2]		Pedestrian crossing out-of-crosswalk[3]	
	Odds Ratio	p-value[4]	Coeff	p-value[4]	Coeff	p-value[4]	Odds Ratio	p-value[4]
(Intercept)	0.91	0.738	**50.86**	0.001***	**6.52**	0.001***	**0.06**	0.001***
Timing of interaction								
Weekend	1.19	0.469	3.21	0.573	-0.94	0.325	0.42	0.284
Poor visibility	0.94	0.656	-3.88	0.260	0.63	0.284	1.59	0.193
Peak hour (ref: Off peak)								
PM peak	**1.28**	0.067*	1.70	0.647	-0.98	0.120	0.92	0.838
AM peak	**1.38**	0.055*	6.22	0.160	**-1.50**	0.044**	0.71	0.490
Study phase (after)	1.10	0.492	-3.60	0.356	-0.02	0.973	0.78	0.559
Pedestrian characteristics								
Runner	1.15	0.602	-10.50	0.131	-1.61	0.175	**3.04**	0.035**
Biker	**0.74**	0.088*	**-13.37**	0.010***	**1.81**	0.036**	**4.04**	0.001***
Vulnerable users	0.98	0.923	-2.09	0.726	**2.80**	0.005***	**2.73**	0.083*
Pet	0.95	0.780	-3.96	0.403	**2.34**	0.003***	1.18	0.743
Grouped crossing	**1.94**	0.001***	**10.06**	0.007***	**-1.06**	0.096*	**0.46**	0.095*
Vehicle circumstances								
Nearside vehicle	0.88	0.275	3.65	0.241	0.27	0.609	1.04	0.909
Sun in eyes	1.15	0.414	**8.80**	0.035**	-0.44	0.532	1.02	0.952
Location characteristics								
RRFB activation (ref: No RRFB)								
Not activated	1.03	0.878	6.01	0.240	0.29	0.734	0.76	0.551
Activated	**2.59**	0.001***	**22.75**	0.001***	-0.56	0.496	**0.04**	0.002**
Pairs (ref: Burlington pair)								
Colchester pair 1	**0.28**	0.001***	**-21.74**	0.001***	**2.35**	0.027**	2.12	0.259
Colchester pair 2	**0.39**	0.001***	-10.05	0.104	**1.93**	0.062*	1.97	0.335
Middlebury pair	**0.40**	0.001***	-9.08	0.115	**3.40**	0.001***	0.82	0.771
Montpelier pair 1	**0.55**	0.009***	-3.46	0.547	**1.88**	0.050**	1.05	0.938
Montpelier pair 2	**2.38**	0.001***	**20.00**	0.001***	0.08	0.940	1.85	0.345
Observations	1522		684		661		684	
R^2 / R^2 adjusted	0.123		0.137/0.112		0.085 / 0.058		0.97/0.084	

[1] Binomial logistic, driver-level

[2] OLS linear regression, pedestrian-level

[3] Binomial logistic, pedestrian-level

[4] Asterisks indicate the level of significance (***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.1). Bold font indicates a statistically significant relationship between the independent variable and improved (blue) and worse (red) outcomes.

of yielding, wait times, and crossing out-of-crosswalk, which may be due to the greater visibility of groups of pedestrians. On the flip side, the presence of one or more bikers crossing is related to worse outcomes in each category. This may be related to bikers' assertiveness when waiting or crossing, or to perceptions of cyclists by drivers. Vulnerable users and pedestrians with pets also have longer wait times, which may reflect a greater level of caution when crossing. Runners and vulnerable users are also more likely to cross outside of the crosswalk. In terms of vehicles' circumstances, those situated with the sun in the driver's eyes have better pedestrian-level yielding, which is counterintuitive but may reflect better visibility in sunny conditions or greater driver caution when the sun is in their eyes. Not surprisingly, most outcomes also vary by location.

Model results for all safety-related outcomes are shown in Table 9, which is interpreted as described above for Table 8, except that all models are binomial logistic; thus only odds ratios are shown. These results indicate that the presence and activation of an RRFB does not have a significant effect.

Looking at the timing of crossings, weekend crossings are more likely to have a risky vehicle stop, which may reflect less routine travel or distracted or impaired drivers or pedestrians. Poor visibility is associated with fewer pedestrians stepping into the roadway before drivers yield, which may reflect heightened pedestrian caution. The second phase of the study is associated with more pedestrians stepping into the roadway before drivers yield, which may be attributable to an unmeasured difference that occurred at one or more locations in the first or second data collection phase. In terms of pedestrian characteristics, vulnerable users are less likely to have a risky vehicle stop, which may reflect greater caution of vulnerable users or drivers in their presence. Runners are less likely to have a risky vehicle stop, which may relate to their ability to cross quickly. As with compliance, there is some variation across locations, although it is more modest.

In general, the models of safety-related outcomes offer lower levels of explanatory power and show fewer significant relationships than the models of compliance outcomes, which may be an indication of no relationship, a relatively weak relationship, or lower statistical power of these models due to high variability in outcomes and/or the lower rate at which some outcomes were observed (see Table 6).

MODEL 2: VARIATION IN OUTCOMES FOR CENTRAL VERSUS RURAL TRANSITION ZONES

We now turn to the evaluation of RRFB effectiveness using our second set of models, which includes variables for central versus rural transition zone location instead of pair-specific location effects. Looking at Table 10, the modeled effects of RRFBs on for driver and pedestrian compliance are similar to those shown in the first set of models, except that these models indicate that the presence of an RRFB that is not activated is also associated with improvements in yielding (albeit less so than when it is activated). The effects of other factors on compliance outcomes are also similar to those found in the first set of models, with the following exceptions. In this set of models, driver-level yielding and pedestrian wait times are better on weekends, poor visibility is associated with greater rates of pedestrians crossing out-of-crosswalk, grouped crossings do not have a significant relationship with pedestrian wait times, sun in the drivers' eyes does not have a significant relationship with pedestrian level yield rate, and peak periods are not significantly related to yield rate. Given the poorer fit of this set of models when compared with the first set of models of compliance outcomes, we posit that many of these differences may stem from unmeasured variation at location pairs that this model does not capture as well rather than additional insights about modeled relationships.

Table 9. Multivariate models of safety-related outcomes (Model 1: Location effects)

Variables	Risky vehicle stop position[1]		Vehicle stops suddenly[2]		Pedestrian in roadway before drivers yield[2]	
	Odds Ratio	p-value[3]	Odds Ratio	p-value[3]	Odds Ratio	p-value[3]
(Intercept)	**2.33**	0.044**	**0.08**	0.001***	**0.33**	0.001***
Timing of interaction						
Weekend	**1.95**	0.070*	0.44	0.156	0.61	0.153
Poor visibility	1.02	0.937	0.85	0.543	**0.71**	0.098*
Peak hour (ref: Off peak)						
PM peak	0.94	0.777	1.05	0.873	0.90	0.612
AM peak	0.78	0.349	0.89	0.746	0.92	0.753
Study phase (after)	0.80	0.323	1.33	0.367	**1.71**	0.018**
Pedestrian characteristics						
Runner	**2.64**	0.087*	1.54	0.352	0.81	0.620
Biker	1.23	0.502	0.56	0.210	0.75	0.345
Vulnerable users	**0.32**	0.001***	0.80	0.668	0.97	0.938
Pet	0.95	0.873	0.67	0.328	0.81	0.477
Grouped crossing	0.75	0.177	0.65	0.158	0.86	0.479
Vehicle circumstances						
Nearside vehicle	0.82	0.303	0.90	0.673	0.99	0.970
Sun in eyes	1.00	0.995	1.05	0.867	0.86	0.529
Location characteristics						
RRFB activation (ref: No RRFB)						
Not activated	0.80	0.472	0.74	0.467	0.73	0.313
Activated	0.85	0.557	1.01	0.981	0.95	0.860
Pairs (ref: Burlington pair)						
Colchester pair 1	**3.34**	0.004***	1.95	0.228	1.02	0.967
Colchester pair 2	1.78	0.117	1.56	0.439	1.31	0.452
Middlebury pair	1.39	0.310	**3.93**	0.005***	**3.40**	0.001***
Montpelier pair 1	**3.74**	0.001***	**2.54**	0.066*	1.10	0.788
Montpelier pair 2	1.58	0.201	2.33	0.115	0.86	0.678
Observations	632		689		689	
R^2 / R^2 adjusted	0.071		0.039		0.043	

[1] Binomial logistic, driver-level, yielding cars only

[2] Binomial logistic, pedestrian-level

[3] Asterisks indicate the level of significance (***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.1). Bold font indicates a statistically significant relationship between the independent variable and improved (blue) and worse (red) outcomes.

Table 10. Multivariate models of compliance outcomes (Model 2: Central / transition zone effects)

Variables	Driver-level yielding[1]		Pedestrian-level yielding rate (%)[2]		Pedestrian wait time (secs)[2]		Pedestrian crossing out-of-crosswalk[3]	
	Odds Ratio	p-value[4]	Coeff	p-value[4]	Coeff	p-value[4]	Odds Ratio	p-value[4]
(Intercept)	**0.48**	0.002***	**47.55**	0.001***	**7.41**	0.001***	**0.09**	0.001***
Timing of interaction								
Weekend	**1.98**	0.001***	8.74	0.119	**-1.66**	0.071*	0.36	0.202
Poor visibility	0.97	0.816	-3.79	0.282	0.45	0.436	**1.81**	0.083*
Peak hour (ref: Off peak)								
PM peak	1.21	0.139	-0.14	0.972	-0.80	0.204	0.90	0.776
AM peak	1.29	0.111	4.29	0.346	**-1.47**	0.048**	0.68	0.419
Study phase (after)	1.06	0.641	-4.41	0.243	0.13	0.828	0.60	0.183
Pedestrian characteristics								
Runner	1.18	0.514	-9.40	0.192	-1.55	0.193	**3.17**	0.027**
Biker	**0.66**	0.012**	**-16.41**	0.002***	**2.17**	0.012**	**3.99**	0.001***
Vulnerable users	0.92	0.646	-3.84	0.535	**2.84**	0.005***	**2.84**	0.072*
Pet	0.97	0.854	-6.01	0.212	**2.30**	0.004***	1.27	0.632
Grouped crossing	**1.82**	0.001***	**9.42**	0.014**	-0.76	0.227	**0.44**	0.065*
Vehicle characteristics								
Nearside vehicle	0.90	0.339	3.70	0.252	0.26	0.625	1.02	0.961
Sun in eyes	1.08	0.644	4.52	0.266	0.06	0.929	0.93	0.839
Location characteristics								
RRFB activation (ref: No RRFB)								
Not activated	**1.34**	0.063*	**13.57**	0.003***	-0.35	0.642	1.15	0.730
Activated	**2.14**	0.001***	**19.78**	0.001***	-0.50	0.480	**0.06**	0.007***
Zone (ref: Central)								
Transition inbound	0.99	0.961						
Transition outbound	0.89	0.415						
Transition (in + out)			1.92	0.592	0.91	0.119	0.94	0.864
Observations	1522		684		661		684	
R^2 / R^2 adjusted	0.050		0.062/0.041		0.063 / 0.041		0.088/0.071	

[1] Binomial logistic, driver-level

[2] OLS linear regression, pedestrian-level

[3] Binomial logistic, pedestrian-level

[4] Asterisks indicate the level of significance (***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.1). Bold font indicates a statistically significant relationship between the independent variable and improved (blue) and worse (red) outcomes.

Looking at the effects of transition zones versus central locations, the models of compliance outcomes show no significant effect of the transition zone (Table 10). This indicates that either there is either little to no effect of the transition zone, or that our data are not sufficiently granular to detect it.

Looking at modeled safety outcomes in Table 11, we again see that model results are somewhat consistent with the first set of models. The presence of an RRFB that is not activated is associated with improvements in the likelihood with which pedestrians enter the roadway before drivers yield, although as in the prior model RRFB activation has no significant effect. We observe better vehicle stopping positions for vulnerable users and overall few significant effects. This set of models points to better safety outcomes on the weekend, and no significant differences in outcomes for runners and in the “after” study phase.

This set of models of safety outcomes indicate that the rate of risky vehicle stopping positions is higher in transition zones for outbound vehicles. This is somewhat contradictory to our expectation that inbound travel is more dangerous as drivers’ perceptions lag their surroundings, but it may instead be that drivers anticipate higher-speed roads and adjust quickly as they leave town. We also observe more vehicle stopping suddenly in transition zones. Overall, this finding may reflect greater risk posed by travelers in rural transition zones, particularly in the outbound direction, or it may be an artifact of unmeasured variation across locations.

Overall the relative stability of the two model formulations gives us some confidence that the results we observe are relatively robust, particularly for models of compliance outcomes. The models of safety outcomes seem to be weaker.

LOCATION-SPECIFIC VARIATION AND ADHERENCE TO DESIGN GUIDELINES

Throughout the analysis, we found evidence that safety and compliance outcomes vary across locations. The difference-in-difference analysis suggested that the effects of the installations on compliance and safety may be worse at the two Montpelier locations (which are not RRFBs), while the multivariate analysis suggested that these outcomes vary across locations without any particular pattern in Montpelier versus other locations, although the latter analysis is set up to capture the direct relationship between location and outcome rather differences in RRFB *effectiveness* across locations.

In light of the variation in findings across locations, we evaluate the extent to which the RRFB installations in this study are consistent with applicable guidelines. We compared these installations to guidance from the interim approval of RRFBs in the Manual on Uniform Traffic Control Devices (MUTCD) issued by the Federal Highway Administration (FHWA, 2018) and Vermont Agency of Transportation Guidelines for Pedestrian Crossing Treatments (VTrans, 2019).

Overall, we found that it is relatively common to place pushbuttons in a location that is not on the pedestrian's left entering the crosswalk, which is not recommended but is allowable in the interim approval. We also observed divergences from RRFB guidance at the two Montpelier locations, where border LEDs were used instead of two rectangular-shaped yellow indicators, making these installations non-RRFBs. The locations reviewed adhered to most ADA requirements for RRFBs that are described in the VTrans guidelines except that three locations did not have a tactile arrow on the push button that indicates the direction of the crosswalk (see Appendix 5 for details). The rest of design guidelines were correctly applied at the locations evaluated in this study. The RRFBs included in this study were installed between June and December of 2021, so this assessment may not reflect adherence to guidelines for older installations. Appendix 5 summarizes our evaluation.

Table 11. Multivariate models of safety-related outcomes (Model 2: Central / transition zone effects)

Variables	Risky vehicle stop position[1]		Vehicle stops suddenly[2]		Pedestrian in roadway before drivers yield[2]	
	Odds Ratio	p-value[3]	Odds Ratio	p-value[3]	Odds Ratio	p-value[3]
(Intercept)	**2.29**	0.032**	**0.11**	0.001***	**0.46**	0.007***
Timing of interaction						
Weekend	1.54	0.211	**0.40**	0.099*	**0.54**	0.061*
Poor visibility	1.08	0.712	0.78	0.349	**0.61**	0.012**
Peak hour (ref: Off peak)						
PM peak	1.01	0.976	1.06	0.851	0.92	0.675
AM peak	0.73	0.224	0.89	0.733	0.98	0.923
Study phase (after)	0.86	0.467	1.22	0.495	1.39	0.112
Pedestrian characteristics						
Runner	2.44	0.114	1.50	0.374	0.77	0.521
Biker	1.29	0.407	0.59	0.249	0.84	0.561
Vulnerable users	**0.33**	0.001***	0.79	0.643	0.95	0.879
Pet	1.17	0.581	0.60	0.207	0.67	0.159
Grouped crossing	0.80	0.281	0.71	0.257	0.98	0.933
Vehicle circumstances						
Nearside vehicle	0.83	0.309	0.89	0.619	0.96	0.800
Sun in eyes	0.85	0.564	1.20	0.530	1.19	0.424
Location characteristics						
RRFB activation (ref: No RRFB)						
Not activated	0.82	0.459	0.65	0.223	**0.52**	0.013**
Activated	1.06	0.821	0.90	0.762	0.76	0.245
Zone (ref: Central)						
Transition inbound	1.22	0.399				
Transition outbound	**1.90**	0.007***				
Transition (in + out)			**2.13**	0.012**	1.24	0.284
Observations	632		689		689	
R^2 / R^2 adjusted	0.071		0.032		0.08	

[1] Binary logistic, driver-level, yielding cars only

[2] Binomial logistic, pedestrian-level

[3] Asterisks indicate the level of significance (***p ≤ 0.01, **p ≤ 0.05, *p ≤ 0.1). Bold font indicates a statistically significant relationship between the independent variable and improved (blue) and worse (red) outcomes.

5.0 SUMMARY OF FINDINGS

Prior research has shown that RRFBs can improve driver behavior, reduce conflicts, and lower crash severity, and that their effectiveness can vary across locations. This literature points to the effects of roadway contexts on outcomes of interest, which may point to locations of greater risk, such as roads without a median. Factors such as posted speed, crossing distance, number of lanes, and vehicle and pedestrian volumes have had mixed effects on outcomes. However, this body of literature does not evaluate RRFB effectiveness in rural and small community contexts, nor does it evaluate RRFB effectiveness in different roadway contexts (e.g. speed, number of lanes, traffic levels). At the same time, it is somewhat extensive and covers a range of roadway conditions (speed, lanes, vehicle, and pedestrian volumes), suggesting that RRFBs may be effective in a range of contexts.

There are several important limitations to this body of knowledge. Limited research has been done on RRFBs in rural contexts, where crashes are more likely to result in fatalities and drivers may be less aware of pedestrians. Additionally, the effect of rural context on RRFB effectiveness has not been evaluated, and no studies evaluate the effectiveness of RRFBs in rural transition zones. Finally, most RRFB evaluation studies lack controlled comparisons, which limits their ability to demonstrate causal effects.

To address this gap, we evaluate RRFB effectiveness in rural areas using a controlled before-and-after study design and a rigorous video recording coding process. We rely on prior research to frame relevant parameters and measures of RRFB effectiveness. We focus on driver and pedestrian compliance and risky interactions. We evaluate the effectiveness of RRFBs in Vermont's rural context using difference-in-difference (DID) analysis and multivariate regression analysis.

We first evaluate whether RRFBs are effective in Vermont's rural communities. Both the difference-in-difference and the multivariate analysis suggest that installing RRFBs in Vermont's small and rural locations leads to compliance and safety improvements. Rates of driver yielding and pedestrians crossing out-of-crosswalk both improve with the installation of RRFBs. Our results also suggest that RRFBs may improve pedestrian wait times, the rate with which vehicles stop suddenly, and the rate with which pedestrians step into the roadway before drivers yield.

Using our multivariate analysis, we also observe the effect of other factors on compliance and safety outcomes. Compliance-related outcomes are worse for bikers, runners, and vulnerable users, while they are better during peak hours, on weekends, and for grouped crossings. Safety-related outcomes are better for vulnerable road users and may worsen in the outbound transition zone.

The difference-in-difference analysis suggests that the effectiveness of RRFBs varies across locations, with some indication that their performance is worse for the Montpelier installations (which are not installed as RRFBs) when compared with other locations. There are no clear differences in RRFB performance across central versus rural transition zones.

The multivariate analysis evaluates the relationship between locations and outcomes but not the effectiveness of RRFBs at different locations. This analysis points to significant differences in outcomes across locations. There was not a discernable pattern of differences in Montpelier in this analysis. Outcomes are largely similar across central and rural transition zones when controlling for other factors, except for safety which may be worse in outbound transition zones although this may be an artifact of unmeasured variation across locations.

Table 12 summarizes the overall effectiveness of RRFBs based on the literature review, the difference-in-difference analysis, and the multivariate analysis. Overall, we find that RRFBs are effective in general contexts, in small and rural communities, and in both centrally located areas and rural transition zones. We also note that diverging from RRFB design specifications may impact the effectiveness of RRFBs, as we observed in Montpelier. In other words, treatments that are similar to RRFBs may not be as effective at improving safety for pedestrians and drivers as correctly installed RRFBs.

Table 12: Summary of findings

	RRFB effect on…	Prior literature	Difference-in-difference analysis	Multivariate modeling
Compliance outcomes	Driver yielding	**Improve**	**Improve**	**Improve**
	Pedestrian waiting time	No Data	**Improve**	**Not significant**
	Pedestrians crossing out of crosswalk	**Improve**	**Improve**	**Improve**
Safety-related outcomes	Driver stopping position	No Data	**Unclear**	**Not significant**
	Vehicles stopping suddenly	**Improve (crashes)**	**Improve**	**Not significant**
	Pedestrians stepping into the roadway before drivers yield	No Data	**Unclear**	**May improve**
Overall effectiveness	Outcomes in general contexts	**Improve**	No Data	No Data
	Outcomes in Vermont's small and rural communities	No Data	**Improve**	**Improve**
	Outcomes in both central and rural transition zones	No Data	**Improve**	**Improve**

RECOMMENDATIONS FOR PRACTICE

When installed in adherence to guidelines, RRFBs present an opportunity to improve pedestrian safety in rural and small communities in Vermont. Below we summarize recommendations for updating the August 2019 *Vermont Agency of Transportation Guidelines for Pedestrian Crossing Treatments* (described in more detail in Appendix 8):

1. Expand the range of roadway types that are considered for RRFB installation to include 3000 to 9000 AADT 2-lane roads with posted speeds of 35mph or less.
2. Add clarifications to prevent incorrect installations such as flashing LEDs instead of rectangular beacons.
3. Add emphasis to ADA requirements such as the use of a tactile arrow pointing in the direction of crossing.
4. Add other considerations for where to install RRFBs:
    a. Locations with shared paths
    b. Locations with concerns about out-of-crosswalk pedestrian crossing
5. Note that RRFBs have been shown to be effective in both central locations and in rural transition zones.

6. Note that RRFBs are not always an appropriate treatment. RRFBs are one of many safety-related treatments. Selecting an appropriate treatment depends on the conditions at each location and the need that the community seeks to address. For example, RRFBs are not intended to reduce vehicle speeds, whereas a number of other treatments are appropriate for this purpose and can be used in Vermont (see the VTrans Vermont Safety Toolbox, which will be released in Spring 2023). RRFBs are intended to increase drivers' yielding, but their use may not be merited at every location as they require maintenance which has a cost, and when maintenance does not occur in a timely manner it undermines the effectiveness of the RRFB.

Finally, we note that education for both drivers and pedestrians may improve the effectiveness of RRFBs. For drivers, education may emphasize the importance of slowing down and coming to a complete stop when approaching a crosswalk with pedestrians present.

Drivers should be aware of the following safe practices:

1. When approaching a crosswalk with pedestrian seeking to cross and/or an activated RRFB, slow down and prepare to stop.
2. Drivers should come to a full stop at a safe distance from the crosswalk and should remain stopped until the pedestrian has completely crossed the street.
3. Drivers should avoid distractions while driving, especially when approaching crosswalks and areas where pedestrians may be present.

Pedestrians should also be aware of safe use of crosswalks and the use of the RRFB itself:

1. Crossing within a crosswalk (with or without an RRFB) is safer than crossing outside of a crosswalk, as drivers are more likely to be aware of pedestrians.
2. Activating an RRFB by pushing the button increases the likelihood that drivers will notice pedestrians and that they will stop, but activating the RRFB is not a guarantee that drivers will stop.
3. Pedestrians should always look both ways for oncoming traffic before stepping onto the roadway, regardless of whether an RRFB is present or activated.
4. Pedestrians should wait for a safe gap in traffic or for vehicles to stop and yield before crossing and they should continue to look for oncoming traffic while crossing, regardless of whether an RRFB is present or activated.

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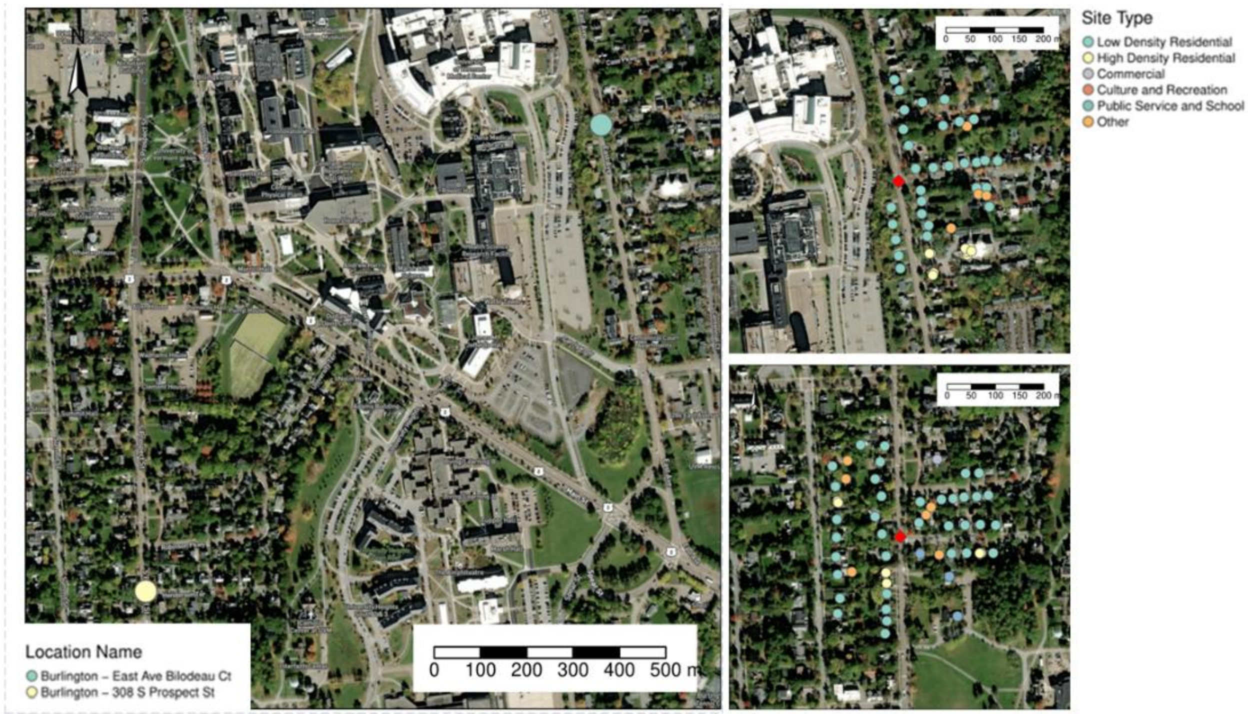
APPENDICES

Appendix 1:

Study locations and surrounding land uses

Burlington:


Location Name
Burlington – East Ave Bilodeau Ct
Burlington – 308 S Prospect St
0 100 200 300 400 500 m
Site Type
Low Density Residential
High Density Residential
Commercial
Culture and Recreation
Public Service and School
Other
0 50 100 150 200 m
0 50 100 150 200 m

Colchester Pair 1:

Colchester Pair 2:

Middlebury:


N
0 100 200 300 400 500 m
N
0 50 100 150 200 m
N
0 50 100 150 200 m
Location Name
Middlebury – US7 – Court St. At Creek Road
Middlebury – main and US–7
Site Type
Low Density Residential
High Density Residential
Commercial
Culture and Recreation
Public Service and School
Other

Montpelier Pair 1:

Montpelier Pair 2:

Appendix 2:

Central and transition zone posted speeds

Pair Name	Location	Posted speed change	Location type	Context
Burlington	East Ave / Bilodeau Ct.	**25**	Treatment	Central
	400 block S. Prospect St.	**25**	Control (crosswalk)	Central
Colchester (Pair one)	Main St. / Cobbleview Dr. (Colchester)	**35**	Treatment	Transition
	US 7 / Chrisemily Ln. (Milton)	40 - **35**	Control (RRFB)	Transition
Colchester (Pair two)	400 block Main St. (Colchester)	**35**	Treatment	Central
	River St. / Rebecca Lander Dr. (Milton)	**25**	Control (RRFB)	Central
Middlebury	US7 Court St. / Creek Road	50 - 40 - 35 -**25**	Treatment	Transition
	Main St. / Pleasant St.	50 - 40 - 35 -**25**	Control (crosswalk)	Transition
Montpelier (Pair one)	VT 12 Northfield / Derby Dr.	50 - **25** -50	Treatment	Transition
	597 Elm St. / N Park Dr.	**30**-25	Control (crosswalk)	Transition
Montpelier (Pair two)	VT 12 Northfield	50 - **25** -50	Treatment	Transition
	VT 12 Elm St. \ Pearl St.	**30**-25	Control (crosswalk)	Transition

Appendix 3:

Intercoder reliability (Krippendorff's alpha) scores

Variable	First check (2021)*	Final check (2021)*	Recap check round one (2022)**	Recap check round two (2022)**
Time pedestrians start waiting	0.99	0.99	1.00	1.00
Time pedestrians start crossing	0.99	0.99	1.00	0.93
Pedestrian wait time	0.94	0.91	0.95	1.00
Weekend	1.00	1.00	1.00	1.00
Visibility (weather)	0.97	0.90	1.00	0.88
Sun in eyes	0.84	0.83	0.81	0.74
Runner	1.00	0.86	0.49	1.00
Biker	1.00	0.94	0.93	0.92
Presence of vulnerable users	0.82	0.85	0.83	1.00
Presence of pets	0.92	0.95	0.96	0.90
Grouped crossing	1.00	0.98	0.98	0.91
Out of crosswalk crossing	1.00	0.90	1.00	0.88
One direction yields the other does not (multiple threat) ***	0.85	0.85	0.74	0.48
RRFB activation	1.00	0.96	0.94	1.00
Pedestrian assertiveness (position on curb)***	0.96	0.96	0.81	0.85
Peak hour	1.00	1.00	1.00	1.00
Pedestrian steps out before the car yields	0.88	0.89	0.82	0.83
Pedestrian step back to prevent accident ***	1.00	0.80	1.00	1.00
Rethink crossing ***	0.94	0.71	0.92	0.85
Car slams on the brake	0.84	0.93	0.86	0.86
Directions	1.00	0.98	1.00	1.00
Direction 1 yielding cars	0.98	0.92	0.97	0.87
Direction 1 non-yielding cars	0.96	0.92	0.83	0.96
Direction 2 yielding cars	0.98	0.92	0.95	0.88
Direction 2 non-yielding cars	0.89	0.91	0.83	0.93
Number of conflicts	0.85	0.88	0.81	0.77
Yield rate	0.92	0.90	0.85	0.92
Average Score	0.94	0.91	0.89	0.89

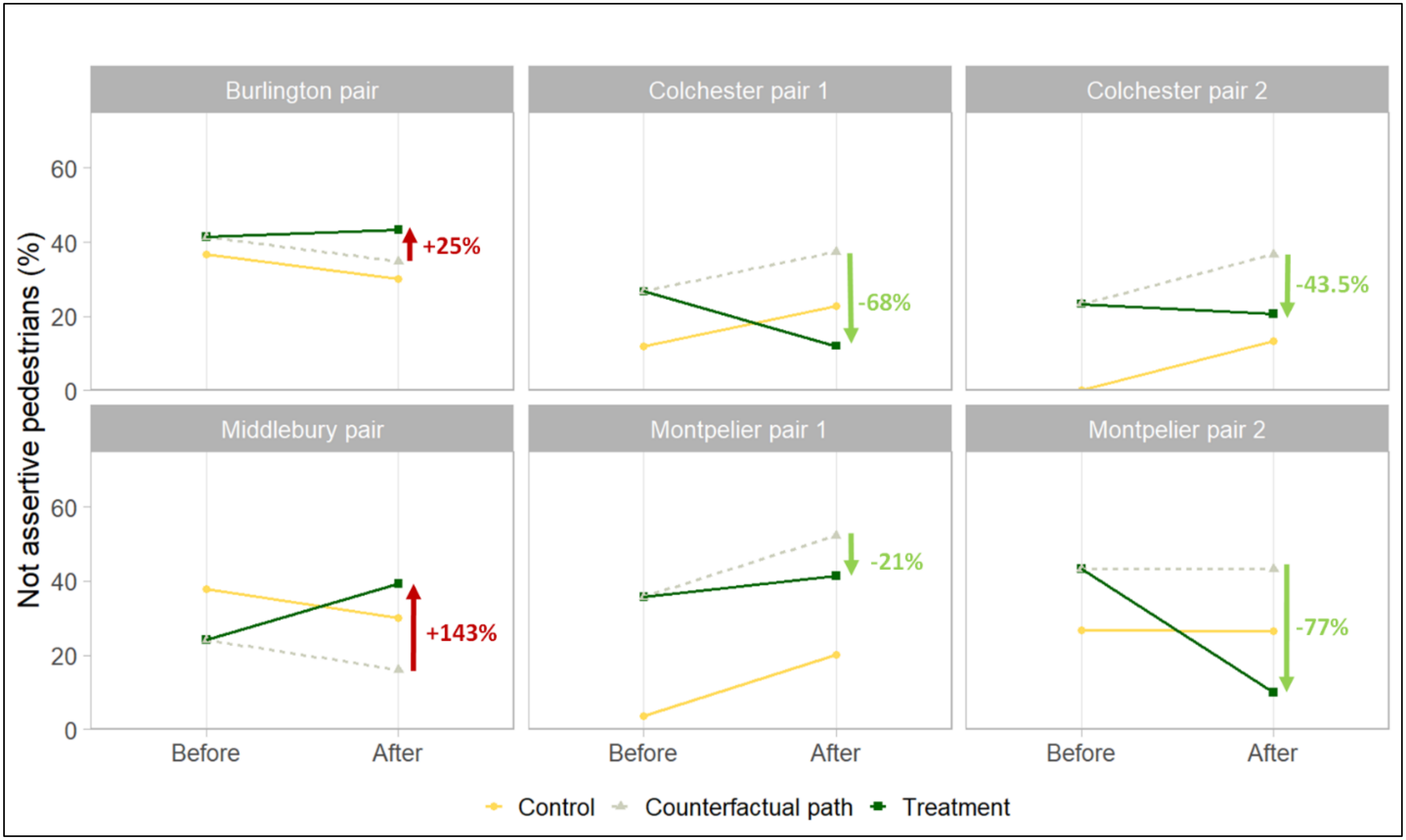
* Before phase: two coders compared to each other in 2021

** After phase: Coder one in 2022 compared with coder two in 2021

*** Omitted from the study

Appendix 4:

Pedestrian assertiveness (stopping close to the curb or on the road)


Burlington pair
Colchester pair 1
Colchester pair 2
Middlebury pair
Montpelier pair 1
Montpelier pair 2
Not assertive pedestrians (%)
0
20
40
60
+25%
-68%
-43.5%
+143%
-21%
-77%
Before
After
Control
Counterfactual path
Treatment

Appendix 5:

MUTCD and VTrans guideline compliance check

Design Element	Burlington	Colchester Pair 1	Colchester Pair 2	Middlebury	Montpelier Pair 1	Montpelier Pair 2
Each RRFB shall consist of two rectangular-shaped yellow indications, each with an LED-array-based light source, each at least 5 inches wide by at least 2 inches high, aligned horizontally, with the longer dimension horizontal and a minimum space between the two indications of at least 7 inches	✓	✓	✓	✓	X	X
W11-2, S1-1, or W11-15 crossing warning signs	✓	✓	✓	✓	✓	✓
Diagonal downward arrow (W16-7P) plaque on the RRFB	✓	✓	✓	✓	✓	✓
Not to be used for approaches controlled by YIELD signs, STOP signs, traffic control signals, or pedestrian hybrid beacons	✓	✓	✓	✓	✓	✓
The outside edges of the RRFB indications, including any housings, shall not project beyond the outside edges of the W11-2, S1-1, or W11-15 sign that it supplements.	✓	✓	✓	✓	✓	✓
"PUSH BUTTON TO TURN ON WARNING LIGHTS" R10-25 sign	✓	✓	✓	✓	✓	✓
Installation fully gate-posted	✓	✓	✓	✓	✓	✓
Pushbutton on the pedestrian's left entering the crosswalk (This is not a requirement but a suggestion. The guideline allows the RRFBs to be installed on the existing poles.)	--	--	✓	--	--	--
Push button less than 5 feet from the edge of the crosswalk	✓	✓	✓	✓	✓	✓
Push button 1.5 to 6 feet (10 feet max) from the curb marking the beginning of the crosswalk	✓	✓	✓	✓	✓	✓
The height of the push button should be no more than 4 feet from the ground.	✓	✓	✓	✓	✓	✓
In the event sight distance approaching the crosswalk at which RRFBs are used is restricted, an additional RRFB may be installed on that approach in advance of the crosswalk to supplement a W11-2 (Pedestrian), W11-15 (Trail) or S1-1 (School) crossing warning sign with an AHEAD: (W16-9p) or distance (W16-2) plaque	NA	NA	NA	NA	NA	NA
The RRFB must be located within the pedestrian crossing area, be detectable by pedestrians with visual or hearing impairments, and have unobstructed forward and side reach	✓	✓	✓	✓	✓	✓

Design Element	Burlington	Colchester Pair 1	Colchester Pair 2	Middlebury	Montpelier Pair 1	Montpelier Pair 2
The RRFB must have a tactile arrow on the push button that indicates the direction of the crosswalk	X (No arrow)	X (Pointing wrong direction)	✓	✓	X (Pointing wrong direction)	✓
The RRFB must have a pedestrian call button that is accessible and detectable by pedestrians with disabilities	✓	✓	✓	✓	✓	✓
Comments	One of the W16-7P plaques is covered with graffiti	Between a traffic signal advisory sign and the traffic signal		At intersection with stop control, confusion about which crosswalk is controlled by the RRFB	Border LEDs	Border LEDs

Appendix 6:

Variable coding guide

DYNAMIC CODING GUIDE

- In Dynamic coding, please SELECT NA if you are not sure and need assistance or have questions. In the end, there should be no NA in the code.
- *If the cars are already stopped (yielding), do not code the crossing*

Revision date:
Description: the date the data are being coded or recoded
Coding format: MM/DD/YYYY
Considerations: update to the latest date you code each time a recoding is in place.

Coder:
Description: Enter the name of the person who is coding
Coding format: Initials
Considerations: D = Dana, L= Lindsay, P = Parsa

Pedestrian based codes

- The following codes are pedestrian centered. In other words, they are coded from pedestrians' perspectives.
- For each crossing, there will be one pedestrian centered data.

Ped ID:
Description: Unique ID for pedestrian(s) for each crossing attempt.
Coding format: 10xxx
Considerations:

- The three last digits are unique pedestrian ID, and the first two digits are the location ID starting from 10.

Location ID:
Description: Unique alphabetic ID for each location.
Coding format: none
Considerations: none

Date:

Description: The Date that the crossing is happening. It is located at the right bottom of the videos.

Coding format: MM/DD/YYYY

Considerations:

- Be careful when dragging the box to copy and fill out the excel sheet. Dates will change and move forward in time.

Weather:

Description: Weather condition as a measurement of visibility when the crossing is taking place.

- Basically, if the weather does not affect visibility like sunny days or cloudy days (not raining or heavily dark) will be coded as good visibility.
- Select Poor visibility if the weather is SNOWY, RAINY, HAZE, STORM
- Select Dark hours when it is night or when the cars have to have their lights on. *It is basically por visibility but we code it this way to distinguish them.*

Coding format: Good visibility (cloudy, sunny), Poor visibility (snow, rain, haze, etc.), Dark hours, NA

Considerations:

- Select NA and resolve later if not sure. There should be no NA in this section at the end.

Sun direction:

Description: In which lane the drivers are facing the sun. have the shadows as reference (utility pole shadows if there is any around).

Coding format:

- facing inbound drivers – if shadows point toward inbound driver (-80 to 80 degrees),
- facing outbound drivers – shadows point toward outbound driver (- 80 to 80 degrees),
- NONE (directly above or not facing any sides or cloudy)
    - Sun is not out (cloudy, rainy, etc.) OR
    - Sun is not in a driver's eyes (directly overhead so shadows are very short or the shadows are perpendicular (80 degrees or more) to the car.

Considerations:

- Base it on shadows (utility poles)
- If the sun is not intense enough (the shadows are not completely distinguishable) select NONE (pay attention to this one)

Runner:

Description: If the pedestrian crossing is a runner or not.

Coding format: Y, N (binary)

- YES:
  - If they walk to the crosswalk but run after or if run all time, select YES (runner).
  - If it is a grouped crossing and there is a runner within the group, select YES.
- NO:
  - If the pedestrian was running but walked in the crosswalk AND walked after, select NO (walker).

Considerations:

- This variable is to capture pedestrian behavior. It does not matter if they are not assertive to the cars that they are runners.
- Do not select runner of the pedestrian runs only in the crosswalk to cross faster.

Biker:

Description: If the pedestrian crossing is a Biker or not

Coding format:

- YES:
  - If they bike to the crosswalk but walk after YES (Biker).
  - If it is a grouped crossing and there is a Biker within the group, select YES.
- NO:

Considerations: none

Grouped crossing:

Description: If there is 2 or more.

Coding format:

- YES:
- NO:

Considerations:

- don't count toddlers and tiny kids that can't walk as group!
- If one ped crosses and a car(s) yield, and then they hold for the next pedestrian, disregard second (not included as a group)
- For each VLC snap, there can only be one interaction
- Two people that are crossing separately, but are within 3 seconds of each other entering the crosswalk, can be considered a group if the car(s) that yielded is still the same (haven't moved)

Presence of vulnerable users:

Description: If the pedestrian crossing is a vulnerable user or not. Vulnerable includes KIDS under 10, people with STROLLER, and old adults or DISABLED. Walking with assistance (cane, wheelchair, walker, someone supporting them), or kids (stroller or under 10).

Coding format:

- YES:
    - KIDS (stroller or under 10)
    - people with STROLLER
    - very old adults or DISABLED
    - Walking with assistance (cane, wheelchair, walker, someone supporting them)
    - If it is a grouped crossing and there is a Biker within the group, select YES.
    - If you are not sure about any <u>be conservative</u>
- NO:

Considerations:

- It does not matter if the user is walking or on a bike. If they are underage (< = 10) or match the description, select as vulnerable.

Presence of pets:

Description: pet

Coding format:

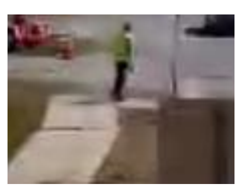
- YES:
- NO:

Time ped starts waiting:

Description: The time pedestrian reaches the crosswalk and decides to cross.

Coding format: Military time format (122112, which is 12:21:12)

Considerations:

- This is the time on the right bottom of the videos.
- A person is starting to wait when:
    - They **<u>< 3</u>** feet of the intersection
        - In the block after L turn 
        - If there is no L turn -> wait till they are within 3ft
    - They are **<u>>3</u>** feet of the intersection AND

            - They are (stopped) and looking at the cars
            - Moving slow towards the curb and looking at the cars
        - If the are assertive at some point and they move back and wait far, do not restart the time. Take the first time he was assertive as the start waiting time.
- A person is NOT starting to wait when:
    - They are >3ft away and looking at their phone or not looking at the intersection.
- If there is a PET make sure you are taking the human as the reference.

Time ped starts crossing:

Description: As soon as they enter the road (not waiting but crossing). In other words, The time pedestrian crosses the threshold where the pavement changes (sidewalk to road)

Coding format: Army time format (122112, which is 12:21:12)

Considerations:

- This is the time on the right bottom of the videos.
- As soon as the pedestrian put their first step on the crosswalk.

Out of crosswalk crossing:

Description: If the pedestrian is crossing outside of the cross walk

Coding format: Y, N (binary)

Considerations:

- YES:
    - Starts outside of crosswalk
    - Diagonal with time outside crosswalk
    - Out of crosswalk is > crosswalk width out (if the width is 8 ft the pedestrian should be 8 feet from the edge of the crosswalk).

- No:
    - Starts in crosswalk (even if they go outside for the last few feet)
- Count the crossing as outside of the cross walk (YES) crossing if the pedestrian in crossing diagonally.
- Count the crossing as outside of the cross walk (YES) crossing if the distance from the crosswalk markings is more than the width of the cross walk (if the width is 8 ft the pedestrian should be 8 feet from the edge of the crosswalk).

One direction yields the other does not (multiple threat):

Description: if the pedestrian is not able to cross because one of the lanes is not yielding.
Coding format: Y, N (binary)
Considerations:

- Select yes if the pedestrian has started crossing and the second car does not yield
- If the second car yields and the ped is on the cross walk (anywhere) select Yes.
- The pedestrian does not have to stop in middle, walking slowly etc…. is acceptable to select a yes
- If the pedestrian started crossing and the car was in the yielding distance you may need to consider "ped start crossing before car yields" too
    - If the car was outside of yielding distance and yields select NO
    - If the car was outside of yielding distance and **does not yield** select yes

Vehicle based codes

Code the first vehicle that is at stopping distance or farther when the pedestrian starts waiting. At some locations where the stopping distance is out of frame, this may be a time-based equivalent.

- Find out about the stopping distance by looking at the screen shot in VLC snap folder where it is flagged.
- If the pedestrian is outside of the crosswalk do not move the stopping distance.
- For the stopping time if the car reaches the pedestrian by the time (like 2.5 secs) count them.
- If the car is seemingly on the stopping distance line (if you are doubtful that if it is in or not) count them in.
- Do not code turning cars if they don't cross the crosswalk.
- Do not code any cars that are coming from the secondary road.
- If the car is already yielded before our start time, do NOT count it.

Each car's characteristics are coded at the stopping distance (or time).
When

Outbound:

Description: This is relative to PEDESTRIAN and is YES if the car is at the outbound lane.
Coding format: Y, N (binary)
Considerations:

- you do not need to code this just select 0 for yield and non-yield cars of there is no car on the out bound lane.

Nearside:
Description: This is relative to PEDESTRIAN and is YES if the car is at the Nearside lane (the lane that the pedestrian first enters the road).
Coding format: Y, N (binary)
Considerations:

RRFB activation (if the ped ever activates):
Description: Whether the RRFB is activated at any time.
Coding format: Y, N, No RRFB
Considerations:

- No RRFB: If there is no RRFB at that location

Pedestrian position (the majority of the time):
Description: choose the position the pedestrian is waiting for the cars to stop.
Coding format:

- at curb – if the pedestrian is waiting at the edge of the curb or <3 ft from it.
- on the road – select this if the pedestrian is on the road waiting for the cars.
    - If there is no side walk (dirt) choose this
- far from the curb - standing in the sidewalk but more than 3 ft away from the edge
- happy feet – select this if the pedestrian moves around or is not assertive that they want to cross
    - talking with others
    - walking back and forth
    - fixing bike
    - playing with their pet
- Moving –
    - if they do not stop moving (fluid motion to the road)
    - if they stop 1 second (very short time)

Considerations:

- if there is a grouped crossing take the closest one to the crosswalk as the reference
- If there is a PET make sure you are taking the human as the reference

Conflicts (ped start crossing before the car yield):

Description: if the pedestrian starts crossing and force the car to stop.

Coding format: Y, N (binary)

Considerations:

- if the pedestrian is crossing and PASSED the center line (crossed nearside lane), don't include the cars that come into the yielding distance in that lane.

Conflicts (ped steps back to prevent accident):

Description: if the pedestrians have to move back or do some evasive maneuvers to prevent accidents.

Coding format: Y, N

Considerations:

This is for when the ped is about to get hit. If they step back and wait to cross later, chose the other option (rethink crossing).

Conflicts (rethink crossing):

Description: if the pedestrians want to cross but decides not to do or rethink it.

Coding format: Y, N

Considerations:

- they have to be on the side walk (have not started crossing yet) to be counted as this.
- This is not the same as pedestrian step back, this is not to prevent accident just to wait more to choose a safe time to cross.
- If the pedestrian yields the right of way to the car and then cross it is not a rethink crossing.

Conflicts (cars slam on the brake):

Description: cars slam on the brake to prevent accident.

Coding format: Y, N

Considerations:

- If the car is in the yielding distance when the pedestrian becomes assertive (those that you disregard) but still slams on brake and yields, count them in as this conflict (select **yes**)
- If the car ends up rolling but you can see it slammed the brake to get to that stage, select yes.

Vehicle's stopping position:

Description: Where vehicle stops relative to the crosswalk.
Coding format:

- Far > 1 car away (length of the same car that is yielding),
  - If not sure, chose the next (close but not in crosswalk)
- close but not in crosswalk,
- invaded the crosswalk (based on bumper).
- Rolling (close or far)
  - If the car slows down
  - If the car slows but not fully yield chose this one (even if the are moving 0.004 MPH)
  - If they are rolling but INVADED, select invaded the crosswalk.
- None – if there was no yielding car

Considerations:

US7 COURT ST. / CREEK ROAD RRFB

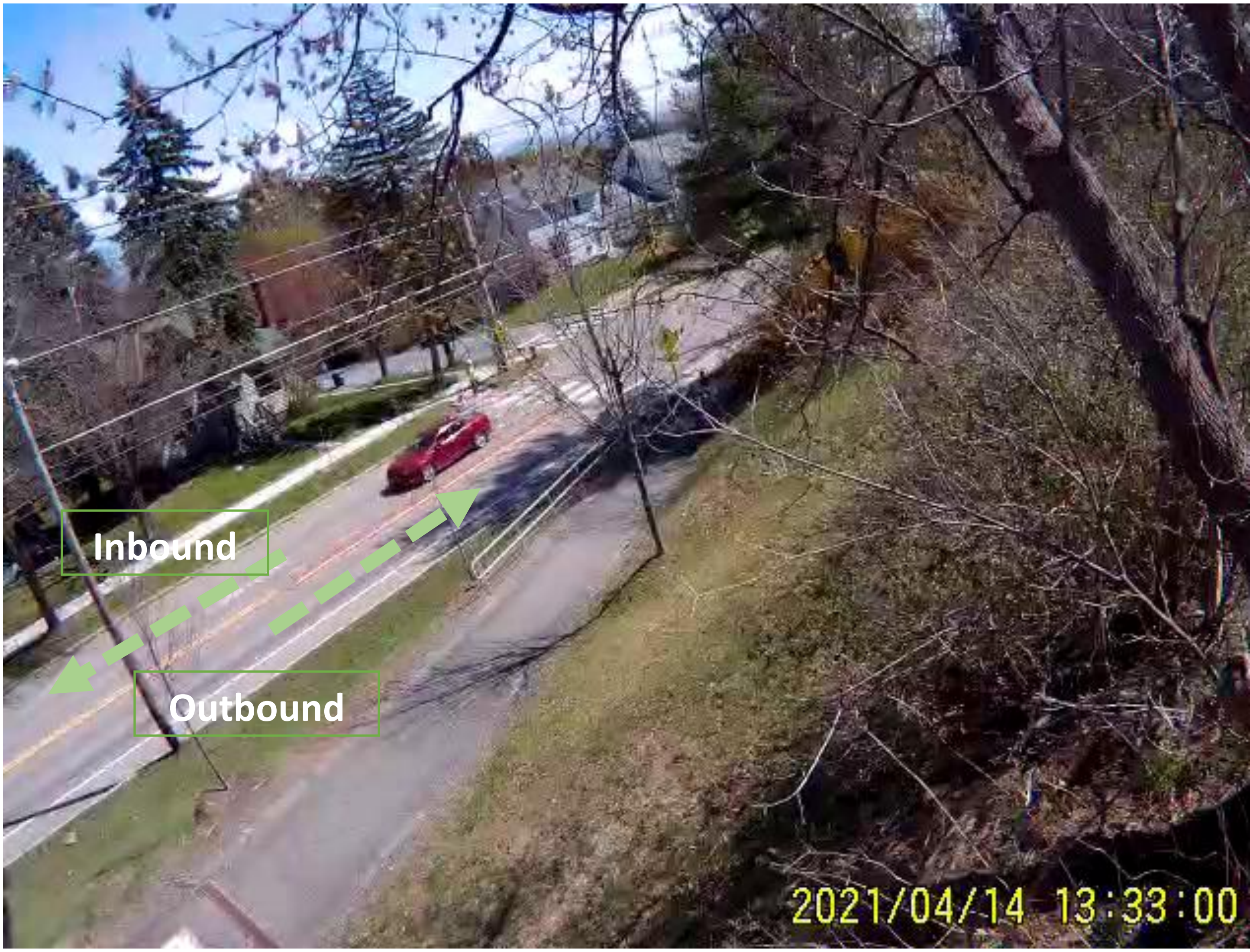
MAIN ST. / COBBLEVIEW DR. (COLCHESTER) RRFB

US 7 / Chrisemily Ln. (Milton) Control

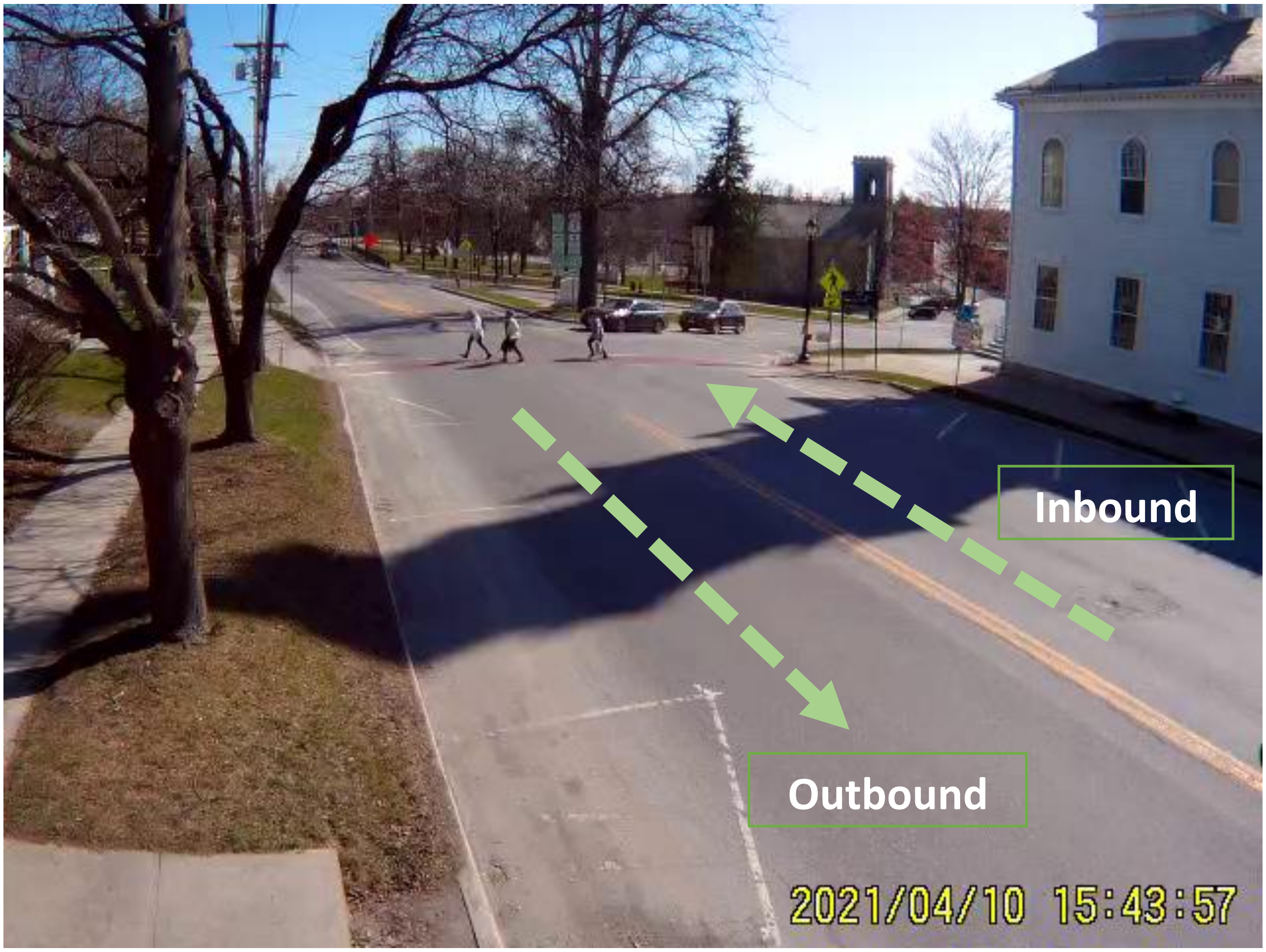
<u>Montpelier - VT 12 Northfield St Derby Dr RRFB</u>

RIVER ST. / REBECCA LANDER DR. (MILTON) CONTROL

MONTPELIER - 597 ELM ST. / N PARK DR. CONTROL



BURLINGTON EAST AVE / BILODEAU CT. RRFB



MIDDLEBURY MAIN ST. / PLEASANT ST. CONTROL

<u>Colchester _ By village scoop icecream RRFB</u>

MONTPELIER - ELM AND PEARL ST CONTROL

MONTPELIER - VT 12 NORTHFIELD ST BETWEEN ROUTE 2 RRFB

BURLINGTON S PROSPECT CONTROL

Appendix 7:

Field review sheet

1st time preparation:

1. Download the countcam2 app
2. Watch the installation video https://www.youtube.com/watch?v=87CS3c7SRYI&feature=youtu.be
3. Print Health and Safety plan and extra copies of the sheets that each person signs, and the study information sheets.

Before departing for each site:

1. Make sure the files are copied and the ram in empty
2. Check items:

CountCam 2s and boosters (confirm batteries are charged)		Power Screwdriver with Socket Bit		Power bank +a connectable phone with spack app		First aid kit	
Spreadsheets + pen + clipboard + ...		Power Screwdriver extra battery		Phone chargers		Sunglass + screen	
measuring wheels		Cutter		Maps		lanyards with UVM ID	
Hose clamps (4 8 10 12)		stepladder		Project Letter (H&S)		sanitizer and wipes	
Duct Tape		screwdrivers		Business cards + Phone numbers		hard hats	
Socket for Hose Clamps		gloves		Safety vests			
Keys + Lock brackets		Weather Stripping					

3. Print:
    a. data collection file to fill in the field
    b. updated location info with details (that Dana posts) of what is approved to put the camera on
4. Insert the locations to your phone and write the location coordinates here! :
5. Make sure the battery, cam, and power screwdriver are fully charged
6. Let Dana know when and where you are headed. Text when you reach.

On site Setup:

1. Park somewhere safe or have a flashing light with you in case you need to park in the road. Park off the travel way, preferably a town side road, or parking lot. Also, have a rotating amber flashing beacon or strobe on the vehicle if parked along the shoulder, and as far to the right as safely possible.
2. Pick a location:
    a. Make sure the pole/tree/etc it has been approved for a camera installation by the appropriate entity
    b. Look for a clear line of sight to the intersection at an appropriate distance to see interactions. Try to avoid any obstructions, e.g. signs, trees, poles, or (if in a tree) leaves that might blow in front of lens.
    c. Try to get a line of sight that includes upstream and downstream to capture yielding distance (may need to measure that out).

200 ft for 45 MPH	
165 ft for 40 MPH	
135.6 ft for 35 MPH	
100 ft for 30 MPH	
85 ft for 25 MPH	
63ft for 20 MPH	

    d. Ideally it is possible to have the clamps / lock at a height above 10 feet, with the camera above
    e. Ideally the line of sight avoids looking directly into nearby homes.
3. Make sure the cam is on and the extra battery is hooked up and you can find the WIFI before putting the pole up.
4. Start recording and make sure the light is flashing then start installation.
5. Check the view with your phone to make sure it is satisfactory.
6. Fix the pole with hose clamps tight.
    a. Use weather stripping to protect trees or wires on utility poles as needed (or weave under wires).
    b. Use two straps spaced at least10 inches distance. Check that it is very secure and won’t rotate.
    c. Ensure that all trash is picked up and in an equipment bag as you go so nothing blows around.
7. Check the view again.
8. Secure the pole with lock.
9. Collect the field data.
10. Mark yielding distance if applicable!
11. Take pictures:
    - First: data collection sheet with the field location filled in.
    - setup,
    - Pole,
    - angle,
    - crossing both approaches,
    - RRFB installations (both sides of both signs at a distance to see which side/direction you’re looking),

- crossing signs,
- speed limit,
- etc
- final photo of the completed field data collection sheet.

On site Data collection table:

Location name		Street that the crosswalk crosses: Cross street or landmark:			
Date, time			weather conditions		
1	number of lanes crossed		Type of lanes (eg. Straight, left turn …)		
2	crossing distance (ft)		Width of crosswalk (ft)		
3	Posted vehicle speeds (mph)		type of cross walk edge		
4	Stopping distance (ft) and its marking or camera signal		Cross walk markings		
5	Notable nearby infrastructure (transportation, land use)	Type: Location:	Type: Location:	Type: Location:	
6	Pedestrian facilities on the road crossed	type	distance	Location	
	Bike lane or path characteristics on the road crossed	type	width	Location	
7	Notable speed/bike/ped signs and/or vehicle speed control measures on the road crossed (speed bumps or tables, speed feedback signs, flashing beacons, etc.) approaching the crossing	Direction: (N-S or E-W)		Direction: (S-N or W-E)	
		Type: Distance from crossing:		Type: Distance from crossing	
8	Vehicle/pedestrian/bike activity in the area (qualitative)				
10	Other observations				

Uninstallation and maintenance:

1. Connect to WIFI if the cam is still on, pause and save the last video.
2. Take the cam off
3. Collect any missed data
4. Deliver the cams back to the office and copy all the videos. (don't delete the file on the cam yet)
5. start charging the batteries, cams, and power screwdriver as soon as possible.
6. Check the videos to make sure you have them all and they are playable. (make a back up)

7. Upload videos to the TRC shared drive (subgroup access\RRFB\data) in a folder indicating which location and date.
8. Upload site photos (including photo of the data collection guide) in a folder indicating which location and date.
9. Scan through all videos to make sure data were collected for most of the 4 days without a major disruptive event and that there are pedestrians using the crossings (if not we may need to consider measuring again).

MUTCD checklist:

Is the RRFB used to supplement a post-mounted Wii -2 (Pedestrian), Si -i (School), or Wi 1-15 (Trail) crossing warning sign with a diagonal downward arrow (W16-7P) plaque, or an overhead-mounted Wi 1-2, Si -i, or Wii -15 crossing warning sign, located at or immediately adjacent to an uncontrolled marked crosswalk? [Y/N] _____ If no, what differs from this requirement? ____________________________________

- Is the RRFB used for crosswalks across approaches controlled by YIELD signs, STOP signs, traffic control signals, or pedestrian hybrid beacons? [Y/N] ___ If yes, is the approach to or egress from a roundabout? [Y/N] ____

- Are at least two Wi 1-2, Si -i, or Wi 1-15 crossing warning signs (each with an RRFB unit and a Wi6-7P plaque) installed at the crosswalk, one on the right-hand side of the roadway and one on the left-hand side of the roadway? [Y/N] ___

- On a divided highway, is the left-hand side assembly installed on the median rather than on the far left-hand side of the highway? [Y/N] ____ If no, is it impractical to do so? [Y/N] ____

[describe why it may / may not be impractical]____

- An RRFB unit shall not be installed independent of the crossing warning signs for the approach that the RRFB faces. If the RRFB unit is supplementing a post mounted sign, the RRFB unit shall be installed on the same support as the associated W11-2, 51-1, or W11-15 crossing warning sign and plaque. If the RRFB unit is supplementing an overhead-mounted sign, the RRFB unit shall be mounted directly below the bottom of the sign.

- As a specific exception to Paragraph 5 of Section 4L.01 of the 2009 MUTCD, the RRFB unit associated with a post-mounted sign and plaque may be located between and immediately adjacent to the bottom of the crossing warning sign and the top of the supplemental downward diagonal arrow plaque (or, in the case of a supplemental advance sign, the AHEAD or distance plaque) or within 12 inches above the crossing warning sign, rather than the recommended minimum of12 inches above or below the sign assembly. (See the example photo that is shown below.)

- If pedestrian pushbutton detectors (rather than passive detection) are used to actuate the RRFB indications, a PUSH BUTTON TO TURN ON WARNING LIGHTS (RlO-25) sign shall be installed explaining the purpose and use of the pedestrian pushbutton detector.

- The predetermined flash period shall be immediately initiated each and every time that a pedestrian is detected either through passive detection or as a result of a pedestrian pressing a pushbutton detector, including when pedestrians are detected while the RRFBs are already flashing and when pedestrians are detected immediately after the RRFBs have ceased flashing.

Appendix 8:

Recommended updates to VTrans Guidelines for Pedestrian Crossing Treatments

Figure 11: Crosswalk Enhancement Options to Consider

Roadway Type	3000 ≤ AADT ≤9,000			AADT >9,000 and ≤12,000			AADT > 12,000		
	≤ 30 MPH	35 MPH	40 MPH	≤30 MPH	35 MPH	40 MPH	≤30 MPH	35 MPH	40 MPH
2 Lanes	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB	In-street sign, RRFB
3 Lanes	Ped Refuge	Ped Refuge	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB, PHB
4 or more Lanes with Raised Median*	AYL	AYL	AYL, RRFB	AYL, RRFB	AYL, RRFB	AYL, RRFB, PHB	AYL, RRFB	AYL, RRFB	AYL, RRFB, PHB
4 or more lanes without raised median	Ped Refuge, AYL	Ped Refuge, AYL	Ped Refuge, AYL, RRFB, PHB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, RRFB	Ped Refuge, AYL, PHB	AYL, RRFB	Ped Refuge, RRFB, AYL, PHB	Ped Refuge, AYL, PHB

5.3.4 RRFBs (Rectangular Rapid Flashing Beacon)

Rectangular Rapid Flashing Beacons (RRFB) are meant to be used to provide supplemental conspicuity to a post-mounted or overhead W11-2 (Pedestrian), W11-15 (Trail) or S1-1 (School) crossing warning sign. The FHWA originally issued interim approval for this traffic control device in 2008 and then, after a brief time of rescinding approval, issued an updated approval in March 2018 (interim IA-21). [If these guidelines are revised after the updated MUTCD guidelines come up, this text should be updated accordingly.]

Deleted: .

RRFBs consist of a pair of pedestrian activated flashing lights installed with a crosswalk warning sign. They should be used in situations where increased emphasis is needed to alert drivers to pedestrian crossings (see Figures 10 and 11). Additional background information on the effectiveness of RRFBs may be found in the FHWA memo found in Appendix B.

Deleted: RRFBs consist of a pair of pedestrian activated flashing lights installed with a crosswalk warning sign.

RRFBs consist of a pair of pedestrian activated rectangular flashing lights installed with a crosswalk warning sign. They should be used in situations where increased emphasis is needed to alert drivers to pedestrian crossings (see Figures 10 and 11). RRFBs have been shown to work when located centrally as well as in rural transition zones, which is the section of road where posted speeds drop as the road enters/leaves a city, town, or village center. Additional background information on the effectiveness of RRFBs may be found in the FHWA memo found in Appendix B.

The following is a list of factors that should be addressed where RRFBs are being considered. These factors should not be interpreted as warrants for RRFBs nor pass/fail criteria for the installation of RRFBs. However, these conditions have been identified as ones to be considered using engineering judgment when proposing RRFBs at crosswalks on State Highways. RRFBs are one of many safety-related

Deleted: The overuse of RRFBs in the roadway environment could decrease not only the effectiveness of RRFBs but those crossings without RRFBs.

treatments. Note that RRFBs are not always merited, and they require maintenance in order to be effective. They are intended for use at locations where there is a need to increase drivers' awareness of pedestrians crossing the roadway. They are not intended as a general safety measure or to reduce vehicle speeds. See the Vermont Safety Toolbox for recommended speed countermeasures that are recommended for use in Vermont communities. RRFBs should be limited to locations with the most critical safety concerns.

1. RRFBs typically work best at locations where special emphasis is required, such as crossings with a high percentage of vulnerable pedestrians (predominately young, elderly or disabled), a shared use path, concerns about pedestrians crossing out of the crosswalk, or a history of pedestrian crashes. See Figure 11 for volume, speed and lane configuration conditions that indicate where RRFBs should be considered.

2. Proven pedestrian safety measures such as median refuge islands and/or curb bulb-outs may be used in conjunction with the installation of RRFBs.

3. RRFBs shall only be used at uncontrolled crosswalks (i.e. not controlled by STOP, YIELD or signals).

4. RRFB's should be considered where the crosswalk has significant nighttime pedestrian

5. Either automatic (passive detection) or push-button activation is allowed. Push-button activation should be installed on the left side of the pedestrian when facing the roadway when feasible.

6. If push-button activated the proper signing shall be attached next to the push button, with the legend "PUSH BUTTON TO TURN ON WARNING LIGHTS" R10-25 sign in the 2009 MUTCD. If push-button activated, the push button shall include accessible features such as the size of the button, amount of force needed to push it, orientation to the crosswalk and it must be accessible from the sidewalk. Additional accessibility features may be included.

7. In most cases, RRFBs will be owned and maintained by the municipality in which they are located. Either a finance and maintenance agreement or conditions within a Section 1111 permit will assign this responsibility for RRFBs installed on State highways.

Additional guidance on some of the design details and considerations for RRFB installation is provided in Appendix A. Any RRFB installation shall follow all of the guidance outlined in the March 20, 2018 FHWA Memo regarding RRFBs (see Appendix B.)

Appendix A –

Guidance on Installation of Rectangular Rapid Flashing Beacons (RRFBs)

In 2008, the FHWA originally granted Interim Approval for the optional use of the RRFB to supplement standard pedestrian crossing or school crossing signs at crosswalks across uncontrolled approaches. Due to an issue with product patents, FHWA rescinded its original approval of RRFBs in December 2017. In March of 2018, a new Interim Approval of RRFBs was issued by FHWA. There were some minor technical changes but in general, the guidance is the same. RRFBs shall not be used for other purposes or inconsistent with the FHWA guidance. Use of RRFBs should be strategic so that they don't become so commonplace that they are ineffective.

A. RRFB Location

In the guidance from FHWA on use of RRFBs, the following is included:

1. An RRFB shall only be installed to function as a "pedestrian-actuated conspicuity enhancement".

2. An RRFB shall only be used to supplement a post-mounted or overhead W11-2 (Pedestrian), W11-15 (Trail) or S1-1 (School) crossing warning sign with a diagonal downward arrow (W16-7p) plaque, located at or immediately adjacent to an uncontrolled marked crosswalk.

3. 3. An RRFB shall not be used for crosswalks across approaches controlled by YIELD signs, STOP signs, pedestrian hybrid beacons (aka "HAWK" signals) or traffic control signals. This prohibition is not applicable to a crosswalk across the approach to and/or egress from a roundabout.

4. In the event sight distance approaching the crosswalk at which RRFBs are used is restricted, an additional RRFB may be installed on that approach in advance of the crosswalk, to supplement aW11-2 (Pedestrian), W11-15 (Trail) or S1-1 (School) crossing warning sign with an AHEAD: (W16-9p) or distance (W16-2) plaque. This additional RRFB shall be supplemental to and not a replacement for RRFBs at the crosswalk itself.

Note: There always should be at least adequate stopping sight distance at an uncontrolled crosswalk. In some cases, there are horizontal or vertical curves or other features that limit advance visibility of crosswalks. These conditions may warrant the use of advance RRFBs.

RRFBs are most appropriate when used at crosswalks with high volumes of school-aged or elderly pedestrians or at crosswalks that have a crash history that indicates that a higher degree of visibility would likely reduce crashes.

Where RRFBs are used, they shall be installed on both sides of the crosswalk with the ped or school signs and down arrows back to back on both sides (this type of installation is called "gate-posting.") The flashing beacons themselves shall face both directions on both ends of the crosswalk.

There is other specific information about the size of the beacon, flash rate, etc. that all can be found in the full 2018 FHWA Interim Approval memo (Appendix B). The beacons should be set to flash for at least the minimum clearance time for a pedestrian signal, which would be the curb to curb distance divided by 3.5 feet/second assumed walking speed.